APPLICATION OF LEAN PRINCIPLES ON SUPPLY CHAIN MANAGEMENT IN CONSTRUCTION THROUGH SYSTEM DYNAMIC MODELING

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ABSTRACT

APPLICATION OF LEAN PRINCIPLES ON SUPPLY CHAIN MANAGEMENT IN CONSTRUCTION THROUGH SYSTEM DYNAMIC MODELING

Supply Chain Management (SCM) is a concept which originates initially in manufacturing industry. ‘Supply’ refers to the ordering, expediting, and delivering of key project equipment, labor, information and materials. ‘Chains’ represents the idea of links within and between factors (people and organizations, and processes). Supply Chain Management (SCM) is considered as the management of all activities required to transform a raw material into a final product in the most time-effective and cost-effective way possible. SCM starts with acquiring raw material and is carried on through the production and distribution of the product to the final customer.

The supply process in construction often has a large quantity of delays and cost overruns related to inadequate management tools and methods. SCM can be used as a management methodology to improve the construction industry performance.

This study aims to present a system dynamic (SD) model for supply chain process in construction. Furthermore, Lean Principles will be applied on the SD model to improve the efficiency and eliminate the wastes and buffers.

ÖZET

İNŞAATLARDA TEDARİK ZİNCİRİ YÖNETİMİNDE YALIN PRENSİPLERİN SİSTEM DİNAMİĞİ MODELLEMESİ İLE UYGULANMASI

Tedarik Zinciri Yönetimi (TZY) imalat endüstrisinden kaynaklanan bir kavramdır. 'Tedarik', kritik bilgi, proje ekipmanı, işçilik ve malzemelerinin sipariş verilmesi, hızlandırılması ve teslimi anlamına gelmektedir. 'Zincirler', faktörler (insanlar ve organizasyonlar, süreçler) içerisindeki ve arasındaki bağlantılara işaret etmektedir. Tedarik Zinciri Yönetimi (TZY) bir ürünün hammadde çıkartılmasından üretimine ve son kullanıcıya dağıtımına kadarki akışının en etkin-zamanlı ve en etkin maliyetle planlanması, kontrolü ve gerçekleştirilmesi için gerekli olan tüm geniş kapsamlı aktiviteleri tanımlamaktadır.

İnşaatlarda tedarik süreçleri çeşitli sebeplerle, sıklıkla büyük gecikmelere maruz kalmaktadır. Bu gecikmeler inşaatta ilave maliyetlere sebep olmakta ve kaynakların gereksiz harcanması anlamına gelmektedir. Buna ilave olarak, ihaleler zamanında sonuçlandırılamamakta ve bu da malzeme ve hizmetlerin tesliminde başarısızlıklara yol açmaktadır.

Yukarıda anılan açıklamalar çerçevesinde bu çalışmada inşaatlarda tedarik zinciri yönetimi için bir system dinamiği (SD) modeli sunulması amaçlanmaktadır. Sonrasında, SD modeli üzerinde Yalın Prensipler uygulanarak verimliliğin artırılması ve fazlalıklar ile tamponların ortadan kaldırılmasına çalışılacaktır.

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1. INTRODUCTION

In most developing countries the process of material procurement, supplier selection, purchasing agreements, acquiring goods, services, management methods and tools are still traditional in construction industry. Procurement process is being done mostly by project managers and superintendents in small and medium size construction companies. Companies prefer to work with limited and short-term suppliers and cost management is playing an important role in industry. Research in the past showed that price cannot be downplayed as a procurement mechanism and its interaction with other factors related to procurement should be considered. Three other factors which could be essential are trust, time and quality. However, in developing countries, price is playing the main role in a company's policies to choose its supplier.

Deadline delays, budget overruns and poor quality are the main challenges of the construction industry as a result of outdated management methods and tools. However, less attention has been devoted to investigating delays and budget over-runs in construction supply process. Previous research mostly considers procurement delays and budget overruns an overall project characteristic.

Supply Chain Management (SCM) can be used as a tool to improve the construction supply process performance. Material flow and information flow are two determinative factors in any supply process. That means any organization which seeks for a good performance in their overall system, needs to have a constant material flow and an excellent communication method.

This thesis focuses on a procurement problem at ECE company. ECE company is a medium size construction company with a focus on residential buildings and hotels inside and outside of Turkey.

The purpose of this thesis is to apply a system dynamics methodology to procurement problem and to determine waste and buffers in the procurement process of ECE company. Subsequently, Lean Principles are used to eliminate inefficient and unproductive segments of this process. Application of System Dynamics methodology gives an understanding of the structure of the supply process and its dynamic behavior.

To apply System Dynamics Modeling in the ECE company supply process, it is essential to identify the main differences between construction industry and manufacturing industry:

- The construction industry is a single client industry (except the housing sector).
- Each project is a unique project.
- The place, equipment and methods change for each project.
- Construction crew and personnel involved in a project is changing consequently in same project or between projects.
- Materials can be either stored at site or at temporary warehouses.
- The process of purchasing, storing, transportation and inventory management is carried out at the construction site

Therefore, based on what is said above and the uniqueness of each construction project, applying System Dynamics on construction supplying management is more complex, compared to manufacturing problems.

2. SYSTEM DYNAMIC METHODOLOGY

For many years, System Dynamics (SD) is being used in various industry and business areas to study and manage their real behavior. SD modeling is a method to answer to problems regarding delays, feedback, nonlinearities and communication of result. The first step in SD modeling is to identify a problem, question or issue. Subsequently, a model would be developed in a way that is similar to real world behavior. Finally, different policies would be applied to design an effective and robust model. Undoubtedly, the stronger and more policies are being used the better of a performance will be achieved and unseen behaviors won't take place.

Forrester was the first author to suggest using System Dynamics modeling in manufacturing industry in his article 'Industrial Dynamics: A major breakthrough for decision makers [1]. He improved his second model in 1961 further and added a more detailed analysis. Figure 2.1 shows the first model proposed by Forrester for a simple supply chain model.

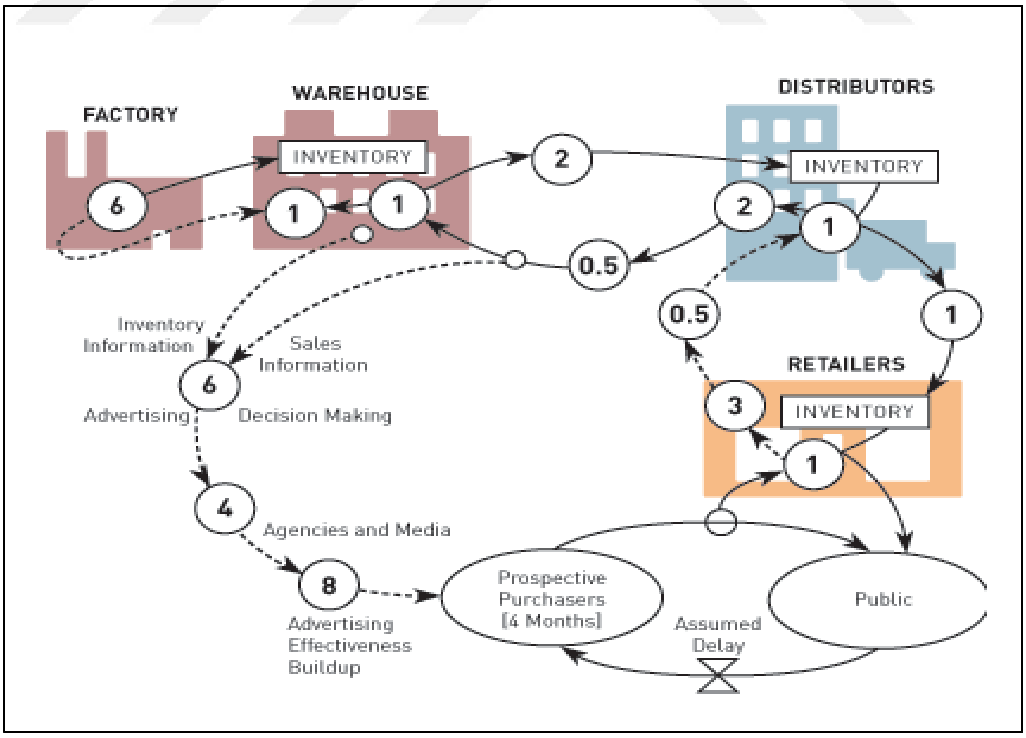

Figure 2.1. The Forrester supply chain model [1].

Forrester's first SD Model is a simple model that consists of factory, warehouse, distributer and retailer, where the flow of materials and flow of information between the nodes of the model are shown. He argued "industrial company success depends on the interaction between the flows of information, materials, money, manpower, and capital equipment" [1].

Forrester's worked has received many critics over the years and has been successfully applied to different cases in industrial, social, environmental and project management systems.

In construction, system dynamics modeling is used by researchers to model project performance [2], change cycle in construction management [3], Risk Analysis [4] and design and build procurement method [5].

The aim of this study is to apply SD methodology to ECE company's material supply process. ECE company is a medium size construction company with concentration on residential buildings and hotels with headquarters in Turkey, operating as fabricator, contractor or as a consortium member. ECE company was established in 1992 and provides services in wide range such as roads, hospitals, shopping malls, landscaping, industrial plants and other industries as a project management and consultancy company.

To understand and model the company supplying process it is necessary to observe how company procurement crew manage their inventories and resources. System dynamic can be a powerful tool for studying the dynamic behavior of supply process and inventories.

3. SUPPLY CHAIN MANAGEMENT

Supply Chain Management (SCM) is a methodology which has its origin from manufacturing industry. SCM came into attention when the Japanese car company Toyota introduced its Just in Time (JIT) delivery system. The system goal was to manage supplies in the right small amount and Just in Time (JIT) to the Toyota motor factory. They aimed to increase inventories drastically and manage the supplier interaction with the production line.

Another pioneer in SMC was W. Edward Deming. He indicated the importance of a strong and trusting relationship between suppliers and companies. He suggested that a long-term relationship achieves loyalty and subsequently increases the quality of the supply process which is a starting point for a cost decrease. After the introduction of SCM by Toyota automotive company, the concept of SCM was rapidly and widely applied to other industries. In addition to Toyota Production System, western researcher like Bubridage and Forrester provided an early contribution to a better understanding of SCM. In general, Supply Chain Management (SCM) is considered as the management of all activities required to transform a raw material into a final product in the most time-effective and cost-effective way possible. SCM starts with acquiring raw material and is carried on through the production and distribution of the product to the final customer. A typical supply chain comprises six elements: suppliers, manufacturers, assembler, distributors, retailers and customers (Figure 3.1).

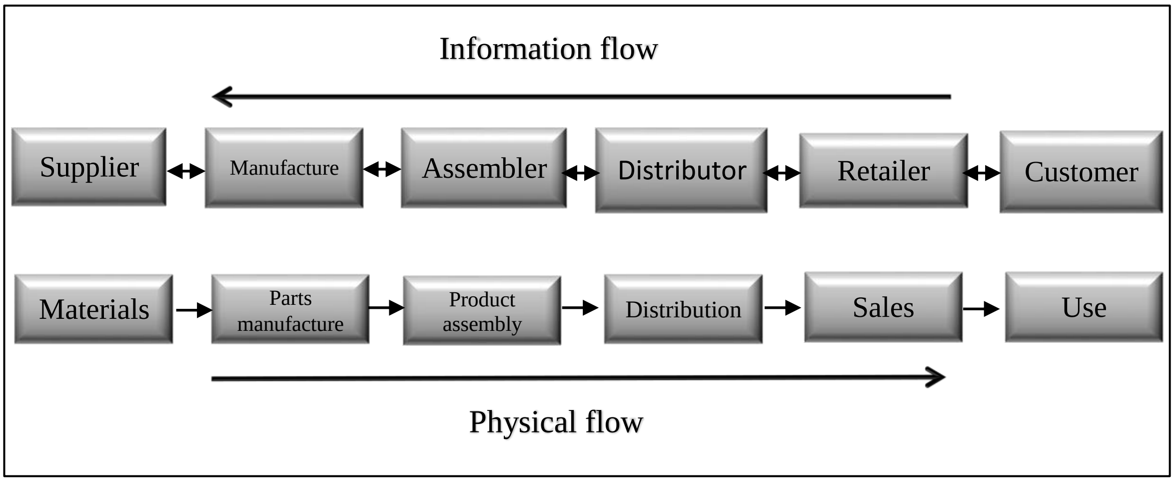

Figure 3.1. General supply chain management

SCM considers all the parts and levels involved in a process as a whole not as individuals. Each part has its influence on the chain and for a thorough performance coordination, alignment and communication between all the entities is an essential need. Cooper *et al.* [6] investigated the elements involved in a supply process and compared these elements in traditional management method and supply change management method. They observed an inventory and cost reduction on the long term in the supply chain management method. However, cost and inventory reduction needed more coordination between elements involved in the system (purchasing, production planning, material management, transportation and distribution). (Table 3.1)

Most of the researchers defined SCM as an active management of all the entities involved in the chain that focuses on maximizing customer value and minimizing inefficiency and unproductivity. To attain such performance the supply chain crew needs to make an observant effort and a continuous development view is required.

3.1. PHYSICAL FLOW

Physical flows are defined as the process in which the raw material is supplied by the supplier, and acquired and stored by the manufacturer, the intermediate product is transformed and stored by the assembler and the final product is transported to the retailer and final customer. (Figure 3.1).

3.2. INFORMATION FLOW

The information flows are described as all the information, orders and future plans which communicate between various supply chain partners to coordinate their long-term schedule, and to control the day-to-day flow of goods and materials. (Figure 3.1).

Table 3.1. Characteristic differences between traditional management and SCM [6].

Element	**Traditional Management**	**Supply Chain Management**
Inventory management approach	Independent efforts	Joint reduction of channel, inventories
Total cost approach Time horizon Amount of information sharing	Minimize firm cost Short term Limited to needs of current transaction	Channel-wide cost efficiencies Long term
Amount of coordination of multiple levels in the channel Joint planning Compatibility of corporate philosophies	Single contact for the transaction Between channel pairs Transaction-based Not relevant	As required for planning and monitoring processes Multiple contracts between levels in firms and levels of channel ongoing Compatibility at least for key relationships
Breadth of supplier base Channel leadership Amount of sharing risks and rewards	Large to increase competition and spread risks Not needed Each treated separately	Small to increase coordination Needed for coordination focus Risks and rewards shared over the long term
Speed of operations, information and inventory level	“warehouse” orientation (storage, safety stock) interrupted by barriers to flows; localized to channel part	“distribution center” orientation (inventory velocity) interconnecting flows; JIT, quick response across the channel

4. SUPPLY CHAIN IN CONSTRUCTION MANAGEMENT

Application of the supply chain management in construction is quite different than manufacturing in that, the manufacturing is a continuous cycle compered of constant production materials, where construction is a linear process of uniquely selected materials and products. To apply System Dynamics Modeling in the construction company supply process, it is essential to identify the main differences between construction industry and manufacturing industry:

- The construction industry is a single client industry (except the housing sector).
- Each project is a unique project.
- The place, equipment and methods change for each project.
- Construction crew and personnel involved in a project is changing consequently in same project or between projects.
- Materials can be either stored at site or at temporary warehouses.
- The process of purchasing, storing, transportation and inventory management is carried out at the construction site.

A construction project supply chain is usually formed by a small or large construction firm, suppliers, engineers, contractors, architects, support professionals and the owner. Suppliers could be small suppliers who provide electrical and mechanical goods or they could be bulk suppliers who provide cement, steel and gravels. The construction firm is awarded the project through a competitive bidding process after which it starts to select a prime contractor, sub-contractor and supplier, depending on the scale of the project.

Due to the uniqueness of each construction project the relationship between all the partners involved in a construction supply chain management is usually short-term which means every new project has its own supply chain.

Time is another critical factor that makes the construction industry different from the manufacturing industry. The starting and ending dates are set in the project schedule at the design and planning stages by the project owner or the construction management company. A construction project is often characterized by deadline delays and budget overruns. Delays are costly and exist in almost all construction projects (between 70 to 80 percentage in residential construction). Delays have legal consequences for contractors and if they don't meet the deadline set by the schedule, they may lose money and go bankrupt.

Another issue making the time factor more complicated for the construction industry is the weather condition. Mostly construction projects are carried out in the outdoors which means the construction progress could be influenced by weather conditions any time these cause a break in the process.

As we discussed before based on the size of a project the prime-contractor may execute the work or use specialty subcontractors to perform different parts of the project. This means the prime contractor may not have full control over the subcontractor's labor because they rapidly move in and out when their work is completed. In other words, construction is a labor-intensive operation which is often characterized by short-time relationships between the construction companies and labor.

In traditional construction methods the coordination and communication between partners involved in a supply chain is very low. Usually there are no encounters between architects and suppliers, contractors and support professionals such as electrical and mechanical engineers.

Traditionally, paper documents and communication are still the main method of information exchange between the partners involved in a project. Change orders, specifications, bill of quantities and architectural and engineering drawings are the common paper documents in construction projects.

Deadline delays, budget overruns, unproductivity and inefficiencies are the result of miscommunication and a lack of coordination. Unlike manufacturing, where learning takes place by repeating the process, in construction changing sites from one project to the next limits the learning. That means any effort to improve the communication and coordination issues is more difficult.

The construction supply chain management (CSCM) could be used as a new methodology to improve and modify the communication and coordination issues discussed above.

Vrijhoef *et al.* [7] introduced the first general model for supply chain management in construction. (Figure 4.1)

They magnify three conclusions based on a case study in construction SCM.

- Firstly, large quantity of waste, delay and cost problems exist in the construction supply chain even when the situation is ideal and normal.
- Secondly, most of those problems are caused in different phases of the process when detected.
- Thirdly, traditional management and lack of communication between partners cause these kinds of waste and problems in the construction supply chain.

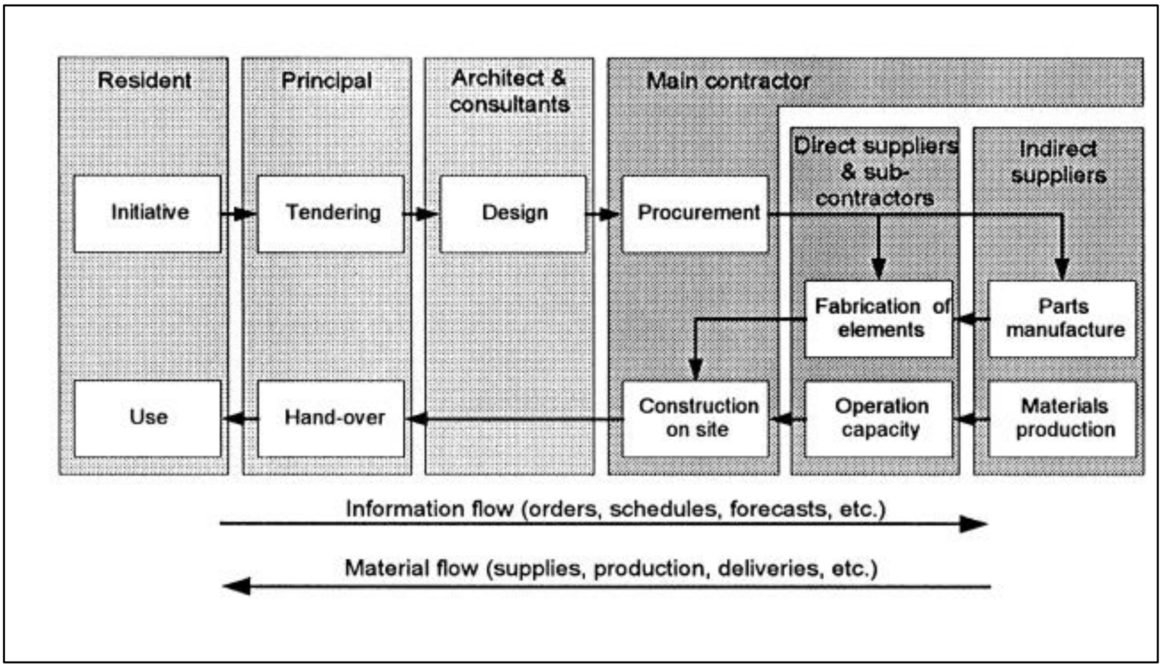

Figure 4.1. General model of the supply chain in construction [7].

Later Briscoe and Dainty *et al.* [8,9] examined the requirements for effectively applying the SCM partnerships in the United Kingdom construction industry with focus on small and medium size companies. They emphasized partners involved in the construction supply chain should have more open relations and pointed out that distrust and uncertainty could be reduced through social interactions between the parties.

Millett and Dainty *et al.* [10] found that there are significant barriers existing when applying SCM and supplier integration in small or medium sized construction companies. It was suggested that parties involved in a project must make a greater effort to take advantage of tow-sided (owner and construction company) benefits of applying SCM and supplier integration.

Lnodon *et al.* [11] and Fernie [12] have studied similarity, difference and behavior of SCM in both construction and industrial organization. Also, they argued the need for a supply chain model based upon the industrial organization model. Love and Irani *et al.* [13] argued the importance of project partner alliances and the suggested an interorganizational relationship. Long-term relationship with supplier and customer to gain trust was suggested as apart of construction supply chain model. (Figure 4.2).

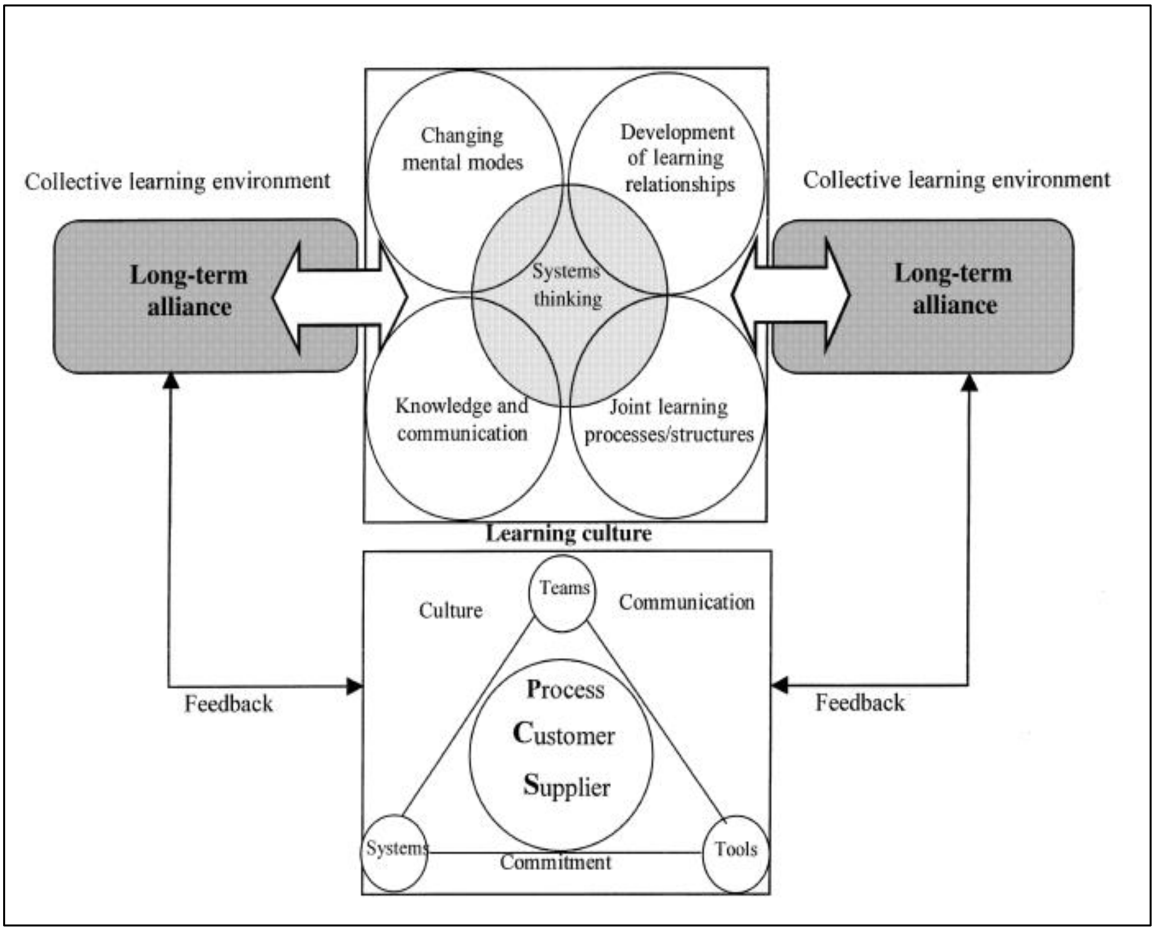

Figure 4.2. A model for alliance [12].

Fernie *et al.* [14] explored the change process in construction and used the concept on supply chain management to facilitate the exploration. Hartmann *et al.* [15] found that the price and trust specific interplay and interaction in selection of subcontractors. The finding shows that neither price and trust can be considered as procurement mechanism.

Lonngren and Rosenkranz *et al.* [16] proposed a supply chain model for the entire life cycle of construction. They described the alliance key factors of success as:

- Central supply chain coordination between partners and decentralization of employee's task management.
- Improvement and application of IT communication skills
- Mutual trust between the partners involved in the supply chain.

Obrien and Formoso *et al.* [17] reviewed key concepts and perspectives in construction supply chain management modeling and they give an overview of existing tools and techniques (Figure 4.3).

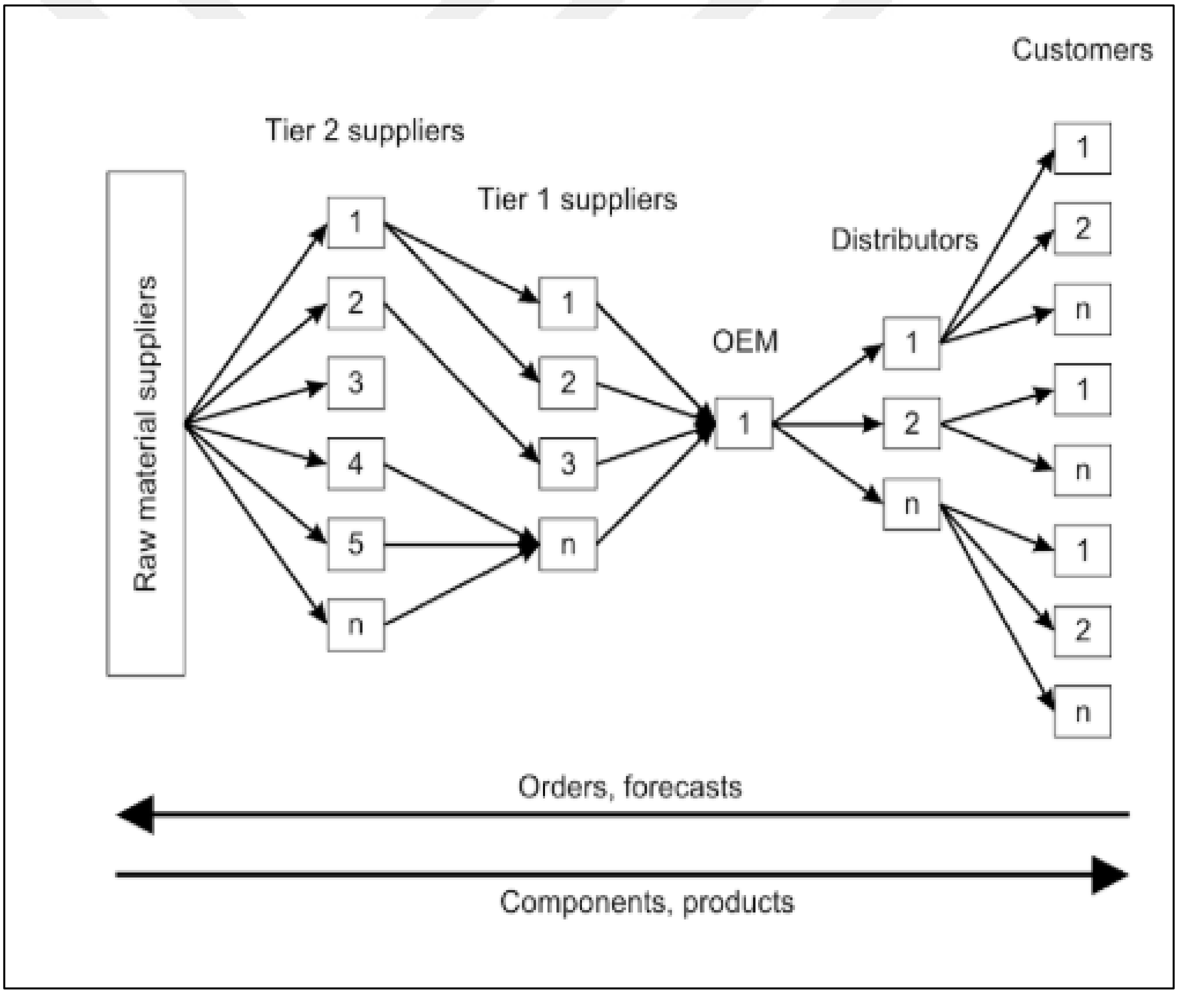

Figure 4.3. Structure of a typical SC in construction [17].

In recent years construction industry is tending to incorporate sustainable and green methodologies. For this reason, researchers paid more attention to the idea of SCM.

This thesis, which is based on analysis of past researches in construction supply chain management and observing a medium size construction company supplying process, presents a System Dynamics (SD) model for construction supply process.

This SD model highlights the inefficiencies and unproductive segments in the construction process. After recognition of inefficiencies, lean principles are used to eliminate these inefficiencies from the process. A new model is recommended after applying the lean principles. After analyzing model, the results are compared with the existed model.

5. ECE COMPANY PROCUREMENT MANAGEMENT AND METHODOLOGIES

5.1. ECE COMPANY

ECE company was established in 1992 with concentration mostly on Industrial & Domestic wastewater collection and treatment. Later the company had widened its work area in hotels, residential, school, shopping mall and various building constructions. The ECE company is categorized as a small and medium- sized enterprise. Currently the ECE company have started 5 small construction sites in Turkish Republican Northern of Cyprus (TRNC). Although TRNC is politically closely tied with Turkey, transporting goods follow the international roles. It means any good that company purchase from Turkey must have the qualification and paperwork for passing the customs.

Being a small country, not all the construction material could be found in the country because production of construction material is limited. So ECE company needs to look for alternative supplier outside of TRNC. Table 5.1 shows the number of main material suppliers and locality of suppliers.

Table 5.1. ECE company suppliers and locality

Material	**Number of Suppliers**	**Locality**
Cement	3 to 5	Local
Steel	3 to 5	Local
Gravels	3 to 5	Local
Other general materials	3 to 5	Local
Mechanicals	5 to 10	Not local (only 10 % local)
electrical	5 to 10	Not local (between 10 to 15%)

5.2. ECE COMPANY'S SUPPLIERS

5.2.1. Local Suppliers

Because the custom qualification is costly and timely, ECE company made contract with 3 local construction suppliers in TRNC which supply projects bulk orders. Usually (90%) of the cement, steel, gravels and other heavy materials are being provided by these suppliers.

5.2.2. Suppliers in Turkey

After procurement team investigates the product cost and delivery time, they may conclude that purchasing material from suppliers in Turkey would be more efficient. Therefore, company has some trusted (company has a long-term trade with them) suppliers in Turkey that provide their needed goods. Usually (70 to 80 %) electrical and mechanical are being provided by these suppliers.

5.2.3. International Suppliers

Occasionally project owners have requested specific goods which is not available in Turkey market. Therefore, ECE company must purchase such goods from the country of origin and overtake the customs qualification and paperwork to transfer to good initially to Turkey and afterwards to TRNC

5.3. ECE COMPANY PROCUREMENT TEAM

Currently company has three procurement employees (procurement manager and two procurement specialists) in company main office at Istanbul. Additionally, two more procurement specialists are active at construction site. The procurement team in Istanbul office is responsible to investigate good's price and cost and also inspecting the supply process. Procurement team based at site is responsible for preparing order lists and managing project's inventories.

5.4. ECE COMPANY INVENTORIES

Company currently has one main inventory based in Istanbul. Company uses this inventory to warehouse, materials and goods which are purchased in Istanbul and Turkey. Whenever company needs more inventory area, procurement team rents a warehouse for temporary inventories. Additionally, company has one main inventory warehouse at projects (TRNC) which is being used to store goods and materials, that are purchased locally or transported to TRNC. Apart from main inventory, company builds small size inventories which are placed at project's site to store materials needed for that specific project. Currently company owns 5 small size inventories on site.

6. MODEL DEVELOPMENT

The next step in systems dynamics process is modeling. Model is specifically is recommended for bulk materials such as steel and mainly concrete supply process. STELLA is the software which is used to create ECE company supply chain model. The model for the existing procurement process has developed after gathering essential information in several meetings with company procurement team manager.

The company's supply chain model consists of an office sector (main office located in Istanbul) and project warehouse sector (local office and Inventories located in TRNC). The procurement manager intends to keep the main inventory level at 10 days and project inventory at 3 days demand cover. Each order takes 2 days to arrive at the main office.

The procurement team after receiving the order immediately send the order to supplier and it takes 7 work days for the order to get to the main inventory located in TRNC.

The supply system can be summarized wit supply chain diagram in case figure 6.1.

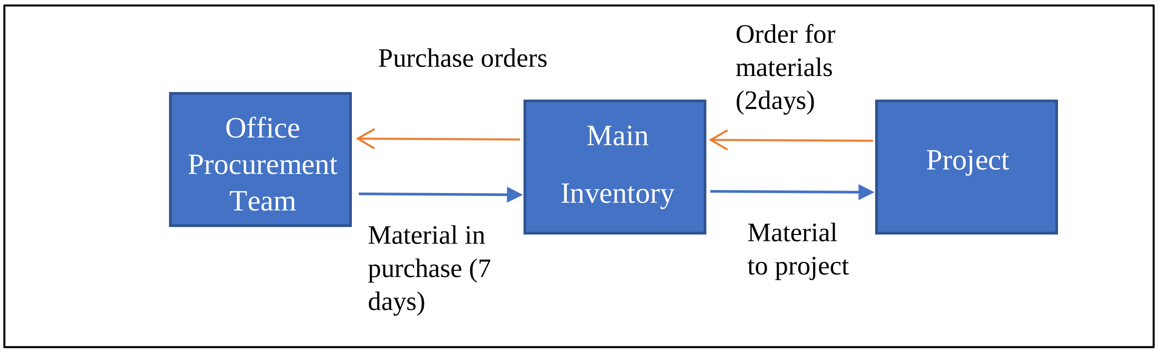

Figure 6.1. Supply system diagram

Following the diagram, a stakeholder map can be prepared as shown in Figure 6.2, summarizing the main stakeholder groups in the supply process. It must be noted that the supplier and government stakeholder do not appear directly in simulation, but they are present, especially in term of new regulation related to geographical sensitivity of region.

Figure 6.2. Supply process stakeholder map.

The management issue that is of concern in this case, is how to manage the inventory ordering system so that inventories are held at stable level, while maintaining continuity of supply to the project to ensure the demand. The procurement team intend to follow the centralized inventory policy and keep the main inventory level at 10 days cover.

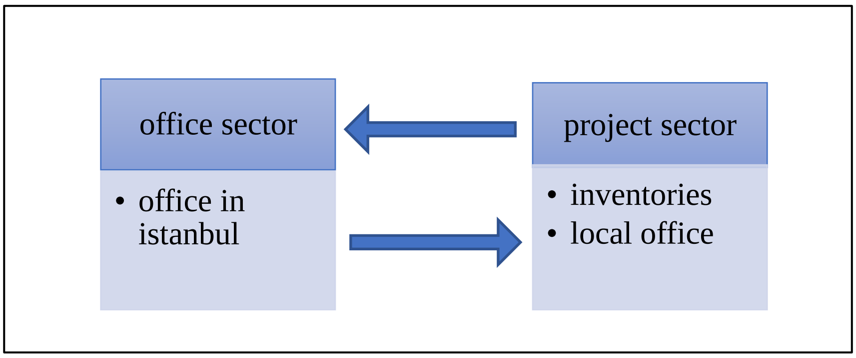

Figure 6.3. A system map of supplying process model.

Although we could consider this model as a single-sector model under centralized control, it is possibly better to conceptualize this system as a tow-sector model (an office sector and project sector) in different locations (figure 6.3). After applying Lean Principle on the model, a single- sector model will be presented.

We also recognize tow material stock (main variables) in the system, i.e. 'case of materials' and 'order for materials.' Materials flow "downstream" from the office sector to the project sector and orders flows "upstream" in the opposite direction.

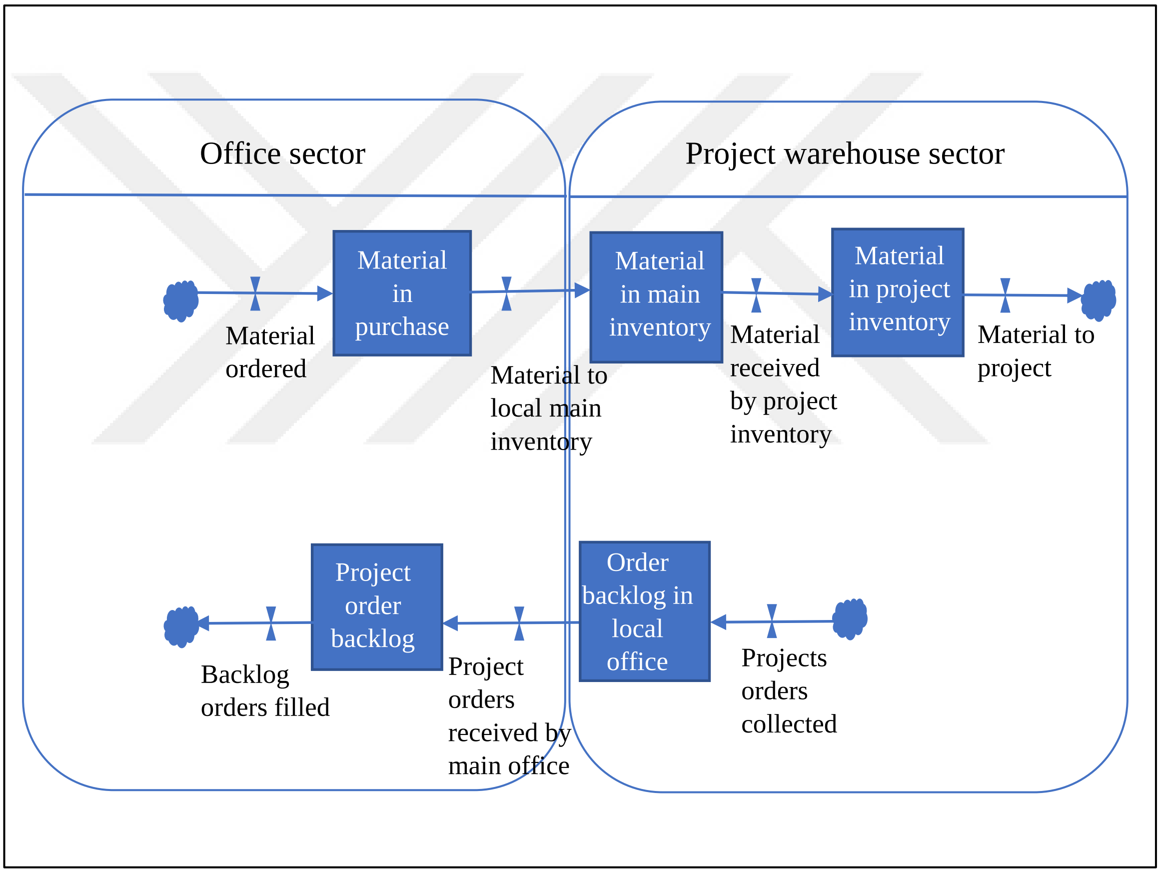

Figure 6.4. Stock and flow in supply process model.

The two categories of material stocks (accumulation) in the system are 'case of material' and 'material orders'. These stocks are in different state and location. Materials flows from stock of 'material in purchase' (Main office in Istanbul) down-stream to stock of 'Main Inventory' and finally to stock of 'Project Inventory' before being consumed by project. Similarly, we recognize that orders for materials can be measured in two different state, 'Order Backlog in local office' and 'Project Order Backlog' at the main office. The stocks and physical flows between them, are illustrated in case figure 6.4. Tow physical stocks and flows were allocated to the two sectors which have identified in the system map in case figure 6.3.

However, although case figure 6.4 illustrates the stock and flow in the system, it does not capture the policy and information links that control changes to these stocks and flows over time. Figure 6.5 shows the physical stock flow diagram with relevant connectors and converters.

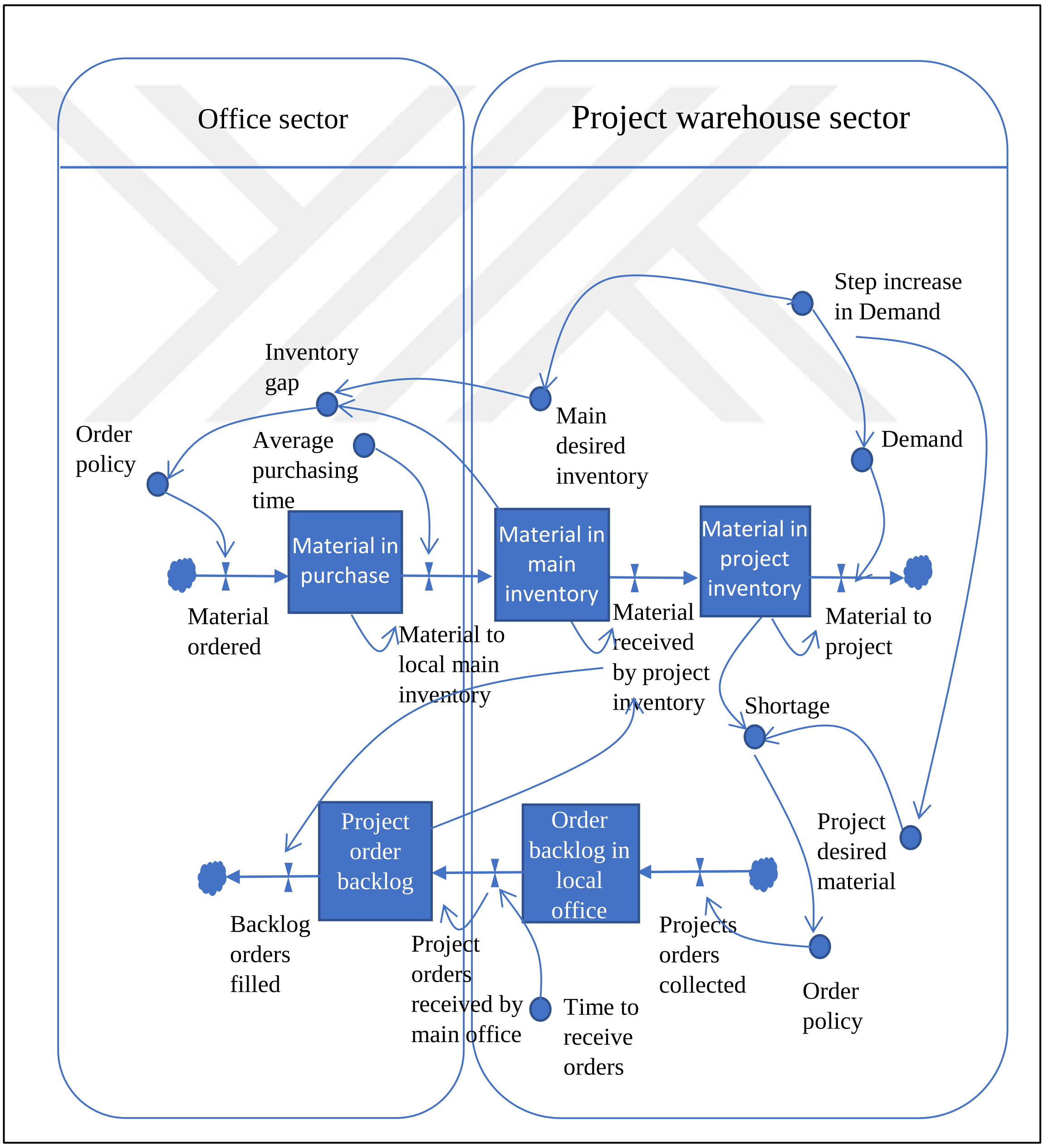

Figure 6.5. Stock and flow diagram of the supply process.

6.1. EQUATIONS FOR THE BASE MODEL

The equations for the base case model for this model are provided in figure 6.6 There is the documented version of equations which are exported from Stella Program. Generally, each equation should be fully documented, including explanation for assumptions contained within the equations and the source of the relationship, or parameter values. Equations are separated into the two sectors, office and warehouse sectors. The first group of equations are the equations for the stock (e.g. Material in purchase) followed by the initial value for the stock. The remaining equations associated with each stock are flows in (e.g. Material ordered) and flows out (e.g. materials to local main warehouse) of the stock. After all the stock and associated inflows and out flows are presented, the converters are provided.

Office Sector

Material_in_Purchase(t) = Material_in_Purchase (t - dt) + (Material_Ordered - Material_to_Main_Warehouse) * dt

INIT Material_in_Purchase = 0

DOCUMENT: Initially there is 0 package of cement in Purchase

INFLOWS:

Material_Ordered = MAX(Order_Policy,0)

DOCUMENT: The cement order from the supplier is determined by the company order policy, set by the procurement manager.

OUTFLOWS:

Material_to_Main_Warehouse = (Material_in_Purchase/Average purchasing time)

Figure 6.6. Equation for the supply process model (base case)

DOCUMENT: it takes 7 days for procurement team to purchase the materials and send them to the main inventory.

Project_Order_Backlog(t) = Project_Order_Backlog (t - dt) + (Project_Order_to_Main_Office - Order_Filled) * dt

INIT Project_Order_Backlog = 0

DOCUMENT: Initially 0 order case in office.

INFLOWS:

Project_Order_to_Main_Office = (Order_Backlog_in_Local_Office/ Time_to_Recive_the_Order)

DOCUMENT: it takes 2 days to confirm the order and send it to main office.

OUTFLOWS:

Order_Filled = Material_to_Project_Inventory

DOCUMENT: Backlog orders filled each day equals the number of cases send to the Project inventory each day.

Inventory Gap = (Desired_Material_in_Main_inv-Material_in_Main_Inventory)

DOCUMENT: The Inventory gap is the difference between the desired main inventory

and actual material in the main inventory.

Figure 6.6. equation for the supply process model (base case)

Order_Policy = (Gap)

Figure 6.6. Equation for the supply process model (base case) (Contd.)

DOCUMENT: the order policy is to order a percentage of the inventory shortage every day.In this case procurement manager ordering all the shortage every time.

Average_ purchasing _time = 7 days

DOCUMENT: it takes 7 days for procurement team to purchase the materials and send them to the main inventory.

Project Warehouse sector

Material_in_Main_Inventory(t) = Material_in_Main_Inventory (t - dt) + (Material_to_Main_Warehouse - Material_to_Project_Inventory) * dt

INIT Material_in_Main_Inventory = 1000

DOCUMENT: Initially there is 1000 package of cement in the main inventory

INFLOWS:

Material_to_Main_Warehouse = (Material_in_Purchase/Average purchasing time)

DOCUMENT: it takes 7 days for procurement team to purchase the materials and send them to the main inventory.

Material_to_Project_Inventory = MIN (Material_in_Main_Inventory, Project_Order_Backlog)

DOCUMENT: once the inventory receives an order material are send immediately

Figure 6.6. Equation for the supply process model (base case) (Contd.)

Material_in_Project_Inv(t) = Material_in_Project_Inv (t - dt) +

(Material_to_Project_Inventory - Material_to_Project) * dt

INIT Material_in_Project_Inv = 300

DOCUMENT: initially there is 300 package of cement in project inventory

INFLOWS:

Material_to_Project_Inventory = MIN (Material_in_Main_Inventory,

Project_Order_Backlog)

DOCUMENT: once the inventory receives an order material are send immediately as long as they are available in the brewery inventory.

Material_to_Project = MIN (Material_in_Project_Inv, Demand)

DOCUMENT: its assumed that demand for cement is met each day as long

as there is sufficient cement in project inventory.

Order_Backlog_in_Local_Office(t) = Order_Backlog_in_Local_Office (t - dt) + (Project_Order_Collected - Project_Order_to_Main_Office) * dt

INIT Order_Backlog_in_Local_Office = 0

DOCUMENT: Initially there is 0 order in local office.

Project_Order_Collected = Project_Order_policy

DOCUMENT: project order is sets by procurement specialist, based of general order policy.

Figure 6.6. Equation for the supply process model (base case) (Contd.)

Project_Order_to_Main_Office = (Order_Backlog_in_Local_Office/

Time_to_Recive_the_Order)

DOCUMENT: it takes 2 days to confirm the order and send it to main office.

Demand = (Step_Increase_in_Demand)

DOCUMENT: this is the daily demand for cement by project, assumed to be exogenous from system

Step_Increase_in_Demand = 100+step (20,20)

DOCUMENT: first 20 days project demand is 100 than it increases to 120

Desired_Material_in_Main_inv = Step_Increase_in_Demand*10

DOCUMENT: project manager intends to keep the material in the main inventory, 10 days cover for project.

Desired_Material_in_Project_Inv = Step_Increase_in_Demand*3

DOCUMENT: Project manager intend to keep the material in the project Inventory, 3 days cover for project.

Shortage = Desired_Material_in_Project_Inv-Material_in_Project_Inv

DOCUMENT: The shortage is the difference between the desired material in project inventory and actual material in the project inventory.

Figure 6.6. Equation for the supply process model (base case) (Contd.)

7. MODEL BEHAVIOR

The model is simulated over a 100 weeks period for cement, and the simulation interval (DT) is set at 0.25 days. The unit of time for this model is weeks. The graphical output for main variables for the base case is provided in figure 7.1 and 7.2. Some of the main stocks i.e., material in purchase, material in main inventory and material in project inventory are shown. Figure 7.1 shows some of the main flows i.e., material to project, project order collected, material to project inventory and material ordered. Stocks and flows which are chosen the main 'decision making' factors in the system. These oscillations are the result of the structure and policies within the system. As we can see the system rapidly produce fluctuation in all three stocks. Especially oscillations in stock of material in project inventory and material in purchase are significant compared to others. 'System Flows' behavior is similar to 'Stocks behavior' as shown in figure 7.2. Although the amount of material which is flowing to project fulfills the demand, there is not a constant behavior in system flows.

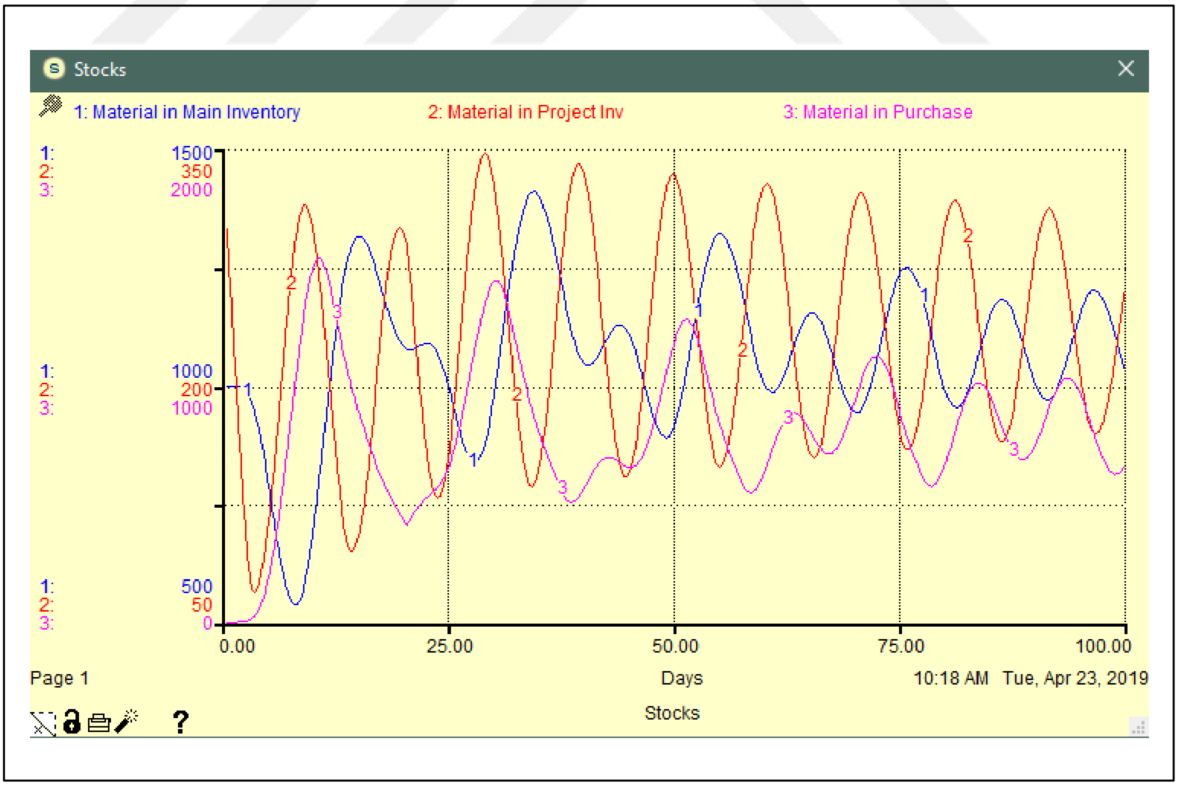

Figure 7.1. Model behavior (stocks)

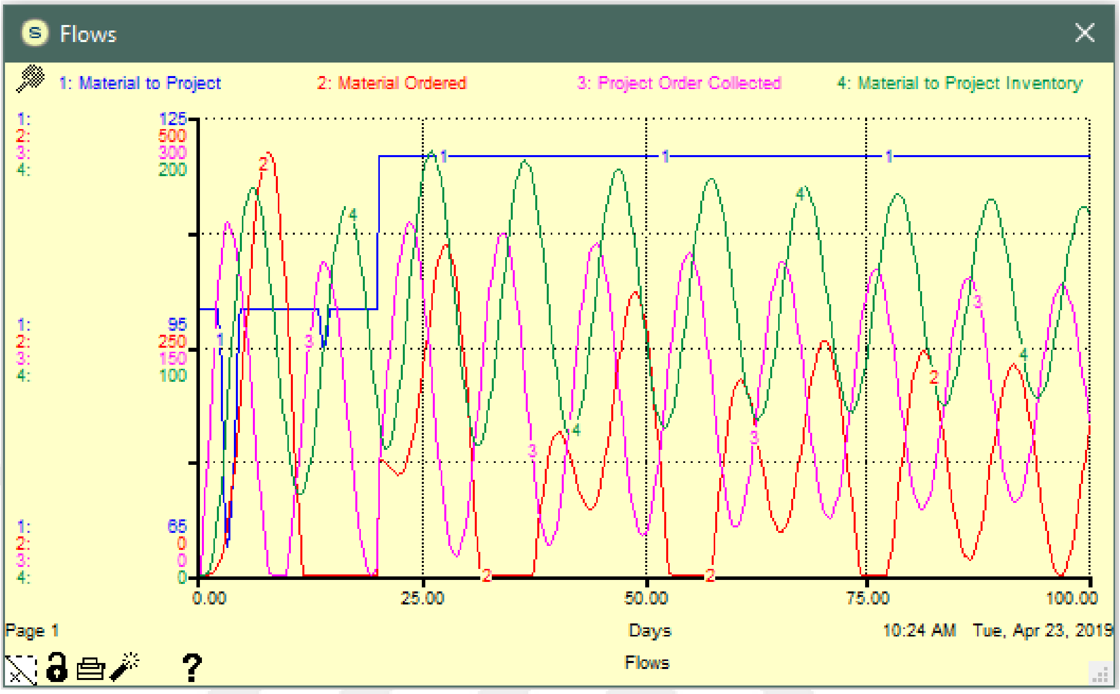

Figure 7.2. Model behavior (flows)

7.1. STOCK BEHAVIOR

7.1.1. Material in the Main Inventory

Stock of 'Material in main inventory' is being shown in figure 14. As mentioned before procurement manger intend to keep the level of inventory at 10 days project demand cover. Project demand is 100 cement packages for first 20 days and there is step increase of 20 at day 21 which change the demand to 120 packages for the rest of time period. However, as we can see in graph the level of materials will never meet the procurement manager desire. In the first 10 days the level of materials is lower than the desire and in the 7th day the material in main inventory is at minimum amount (540 case). We can also see the maximum amount in day 34 (1400 case). As we pass day 12 graph shows that material inventory usually is more than desired material which means more space needed (Figure 7.3).

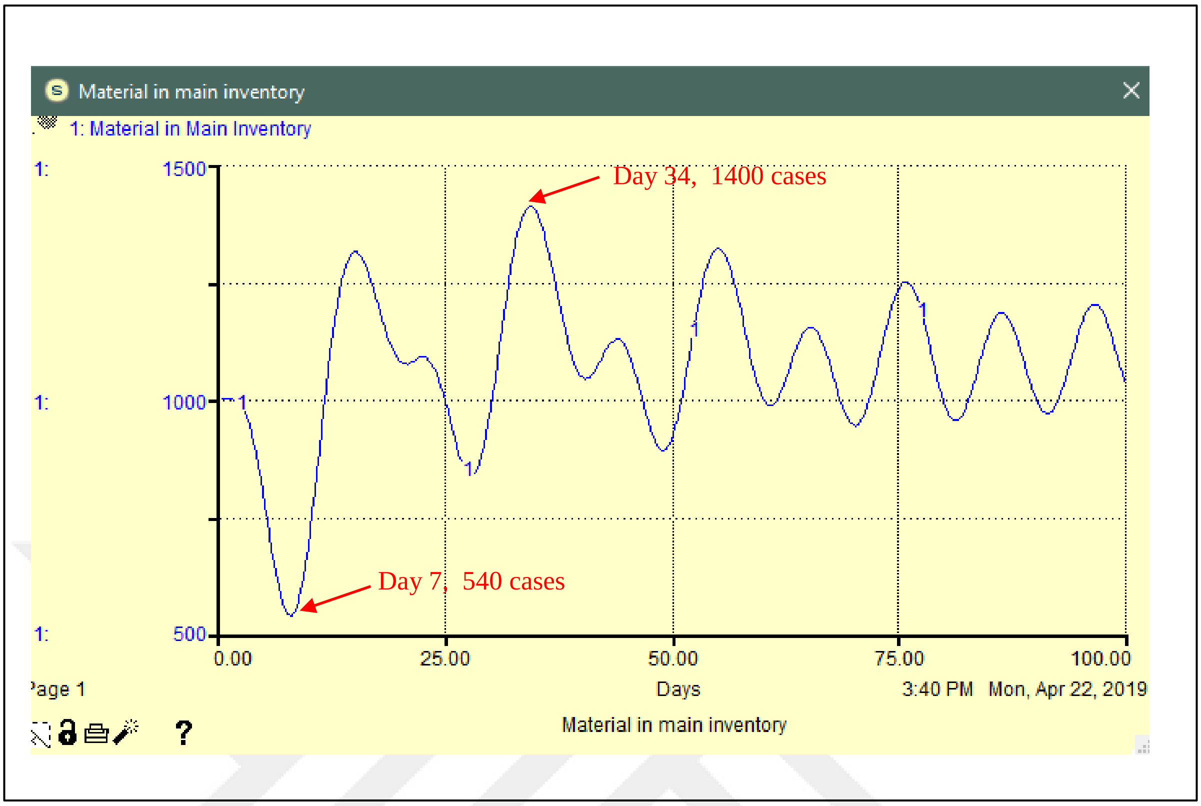

Figure 7.3. Material in main inventory

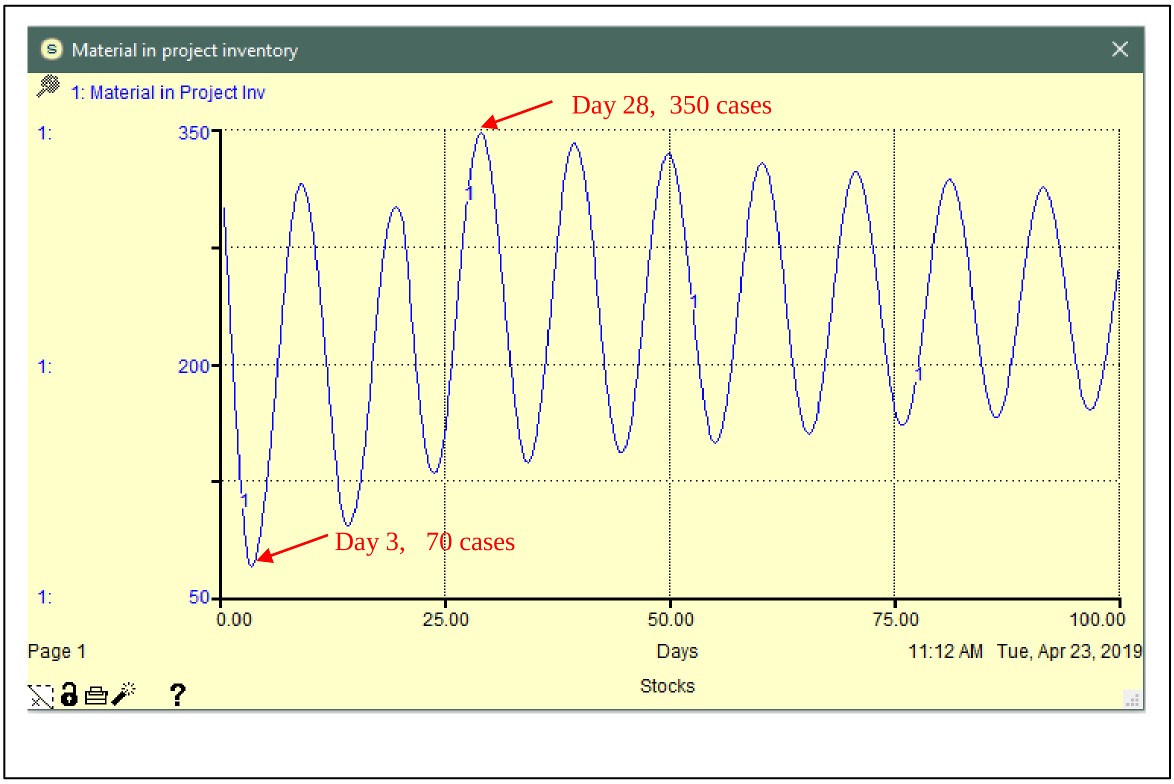

Figure 7.4. Material in project inventory

7.1.2. Material in the Project Inventory

Stock of material in project inventory is being showed in figure 15. Desired material for this inventory is 3 days project demand cover. Same as the "stock material in main inventory", this stock also has rapid fluctuation and unstable behavior. As shown in graph the minimum amount is 70 at day 3 and maximum amount is 350 at day 28. Any delays and problem in supplying process can stop material flow to the project because there is not a stable storage for project (Figure 7.4).

7.1.3. Material in Purchase

Material in purchase stock fluctuation is dependent to the company order policy and desired main project inventory. As we can see as time goes further the graph of material in purchase tends to get more stable. The maximum material in purchase is 1540 at day 10 and minimum is 409 at day 20. A stable and linear graph would be preferred by company procurement team (Figure 7.5).

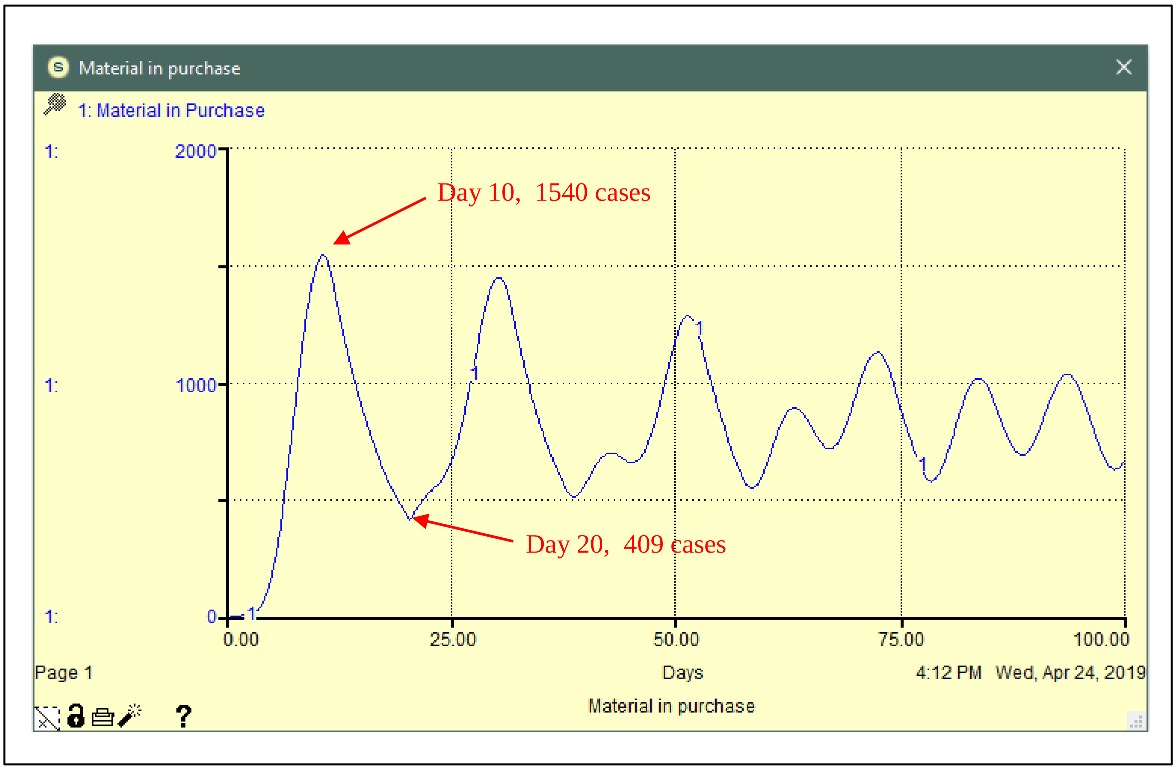

Figure 7.5. Material in purchase

7.2. FLOW BEHAVIORS

7.2.1. Project Order Collected

Project order daily demand is 100 package the first 20 days. After day 20 daily demand increase to 120. Procurement team strategy is the keep the project inventory level at 3 days project demand for any unseen occurrence or supplier problems. Project order collected flow is related with existence material in inventory. It means every time the amount of material drops down lees than desired, orders go to local office. As we can see in the graph the fluctuation is happing rapidly and every day the amount of material needed is different which makes it harder for the procurement team to stick with the daily order (Figure 7.6).

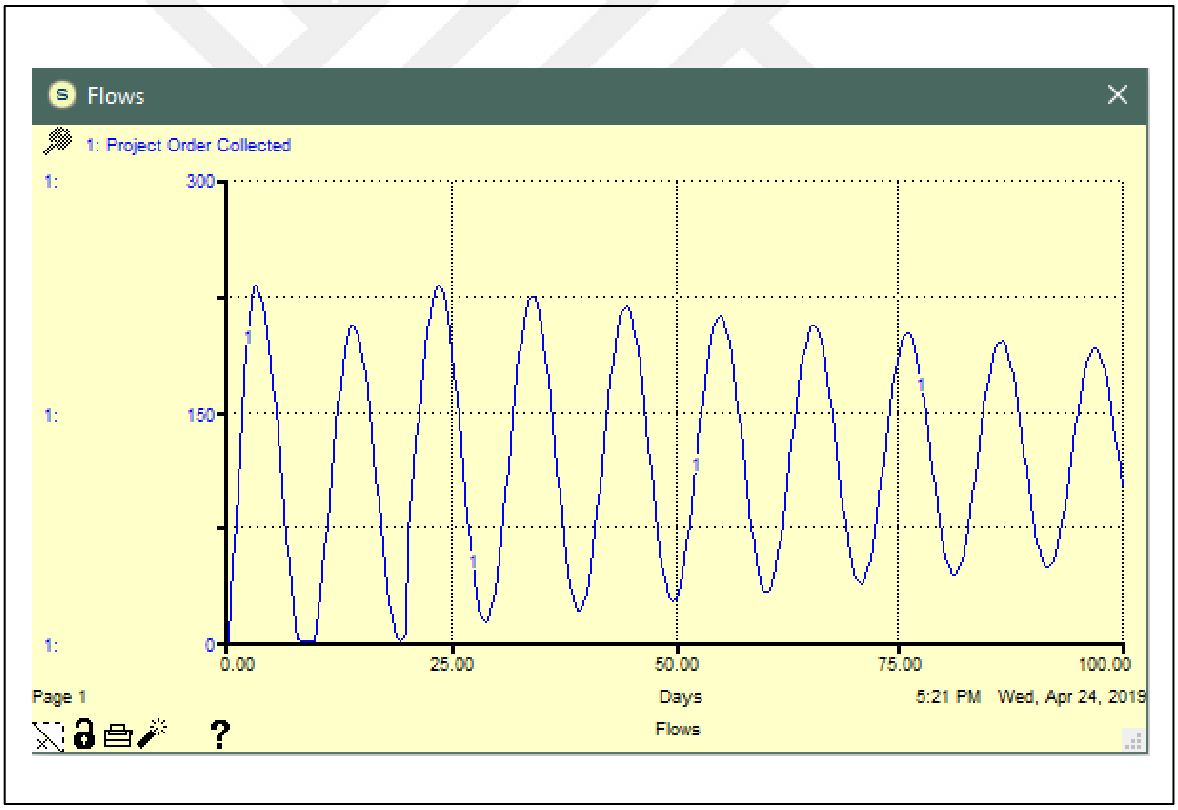

Figure 7.6. Project order collected

7.2.2. Material Ordered

Material is being ordered based on a desired main inventory level which is equal to 10 days project demand. Company policy is to always buy material in bulk and store them at the main inventory in order to prevent money loss related to inflation. Same as other flows there is daily change in orders which is hard to keep up for the procurement team.

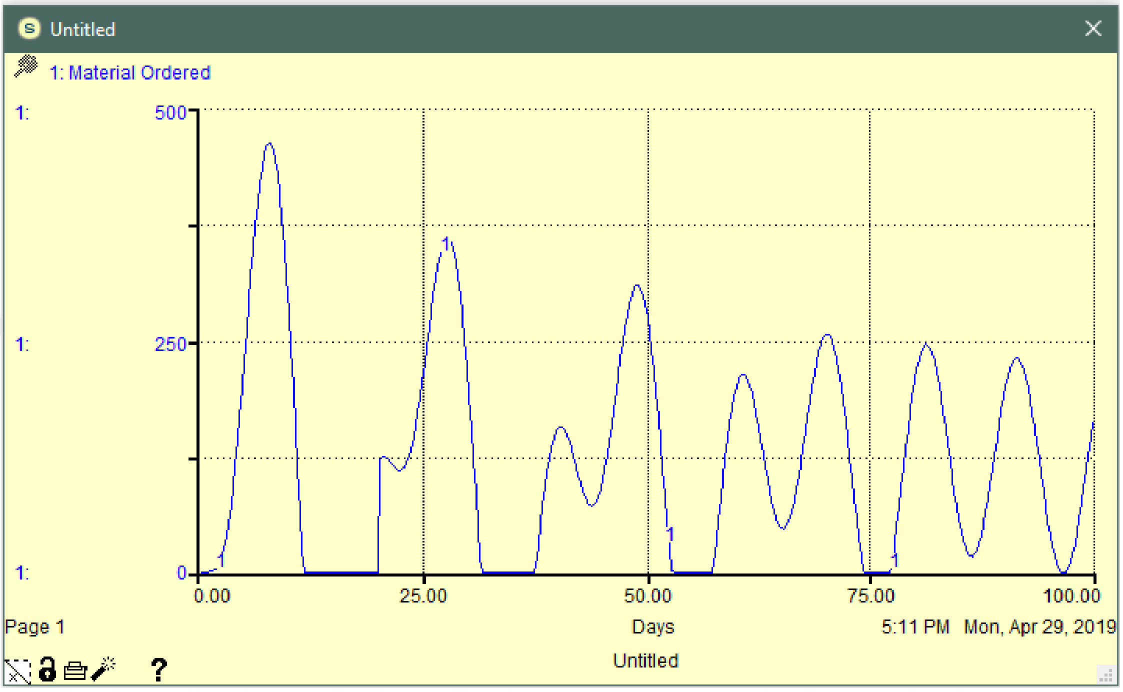

Figure 7.7. Material ordered

7.3. VALIDATION AND VERIFICATION

Soundness and usefulness of a model should be checked before using a model for policy analysis or any kind of application. There are many tests that can be used to validate a system dynamics model. Tests which can be used to validate the model can be outlined as below:

- Verification test: these kinds of tests are used to verify the structure and parameters of the real system which has been copied down to the model.
- Validation test: these kinds of tests are focusing more on the fact if the model is having the same behavior as the real system.
- Legitimation test: these kinds of tests can be applied to check that the model is following the rules and laws of the system.

By applying these tests, one can make sure that there is no major omission in the model representing the real system and vice versa.

The following steps were applied to the model that is proposed for the existing real system that was investigated in this thesis, to assure validity and verification of the model:

- The dimension on the left side of the equation can be converted to the dimension on the right side which shows the model is dimensionally valid.
- The model did not produce any negative and unrealistic value.
- The model behavior is plausible. This means the effect of a change in any of the variables on the model's behavior becomes predictable.
- Materials that entered and those that left the system along with materials that are still remaining in the system are being accounted for. In other words, no material is missing in the model.
- All equations in the model have been fully documented and justified.

8. LEAN MANAGEMENT

8.1. LEAN MANAGEMENT IN MANUFACTURING

International trading became an important part of modern manufacturing by the start of the twenty-first century. Subsequently, mass production became more challenging and new production process planning was needed. Big organizations who were looking for a proper contribution from the new market, especially automotive organizations had to find new methodologies and tools to adjust. Lean Management (LM) was suggested by the Toyota automotive company to overcome the modern market problems and introduce effective and efficient production planning.

Lean Management (LM) is described as a customer driven methodology focusing on production at the lowest cost, by eliminating all possible waste that exists in a production process from a customer's viewpoint. The meaning of "Value" was re-described by putting the customer first. Thereby meaning the organization needs to respect the customer's wishes and production should follow a process on which the customer is willing to spend his or her money. In other words, it aims at minimizing waste without sacrificing productivity. Lean management also takes into account waste created by overburden and unevenness in workloads.

The concept of lean management originated in the Toyota car company after the Second World War. Ohno and Sugimori *et al.* [18] were pioneers in lean manufacturing when for the first time they published Toyota Production System (TPS). They described TPS as consisting of two sections:

- Just in Time (JIT) production system
- Respect to human system

Along with high participation of employees and waste elimination.

Later, Monden [19] presented the just-in-time production system in western countries. He described the magnitude of small size orders, mixed production processes, sophisticated workmen and continuous improvement in JIT delivery system.

The general term "LM" was mentioned for the first time by Krafcik [20] in his master's research at MIT University. The research intended to link the Japanese automotive industry's remarkable accomplishment to the western industry's. Soon after that, Womack and Jones *et al.* [21] published the book "The Machine that Changed the World" and explained the LM concept in more detail.

Womack and Jones *et al.* [22] defined LM as a new integrated production model compared to traditional mass production which creates the same output but utilizes less input. They believed supply chain management, product development and operation management are improved by the new lean management methods, tools and strategies.

Liker [23] describes LM as a philosophy which eliminates waste and reduces the delivery time in the production flow. Blackstone *et al.* [24] defined lean management as a philosophy that focuses on the minimization of time as well as resources consumed in the different parts of a process. All the non-value tasks that exist during the design, purchasing, production and transportation stages should be identified and eliminated. Multi-skilled and sophisticated workers should be used in all stages of the organization.

Howell [25] sees LM as a way toward perfection and is a thoroughly customer driven methodology which is totally different from mass and craft production systems. Lean management's objective is to apply its techniques and ideas to different stages of the production process line aiming to optimize performance.

Liker *et al.* [26] mostly focused on low cost and time delivery benefits along with quality products in the lean management. Seth *et al.* [27], Worley [28], Antonakis *et.al* [29], Holweg [30], Taj *et al.* [31], Alves [32], also give various definitions of lean management as a systematic removal of waste, a manufacturing paradigm, an integrated manufacturing system, a philosophy, a multi-dimensional approach and a model which emphasizes the elimination of waste and increases the value perception of the customer with a continuous improvement.

Lean management had its journey through the last 4 decades and has undergone vast changes and improvements. Lean management is now being used extensively in business, production, manufacturing, marketing, healthcare, software development and construction industry.

8.2. LEAN PRINCIPLES

The National Institute of Standards and Technology describes lean management as a systematic approach to identifying and eliminating waste through continuous improvement, flowing the product at the pull of the customer in pursuit of perfection.

Three important pillars of lean methodology are:

- The customer’s perspective defines the value
- Waste elimination (non-value activities)
- Achieving perfection with steady improvement

After many years of evolution in different industries, Lean Principles are described by Lean Management Institute as follows:

Principle 1. Customer viewpoint specifies value

Value means that problems should be solved for the customer. Any activity a customer is willing to spend his or her money on. Waste is considered as any effort that doesn’t add any value to the final product. Thus, the value an organization is trying to deliver should be known.

Principle 2. Map the value stream and eliminate all non-value stages in your process

According to the value stream principle the workflow of a company needs to be mapped. All functions and manpower used to deliver a final product to the customer should be mapped. Mapping makes the non-value parts visible for the organization and helps to find who is responsible for that part and how to eliminate it without decreasing productivity and efficiency.

Principle 3. Make your product flow steadily to customer

A smooth work flow is the next step after mapping your value stream. Development of a process is a matter of time and steady teamwork. Interruption and delays are the parts of the process. By breaking tasks down in smaller stages and having them mapped it will be simpler to remove problems from the system.

However, by map streaming the process and breaking work into smaller categories, it will be easier to removes obstacles in your process.

Principle 4. Make sure the system has a pull system

When the workflow is stable it means the system can deliver value faster. However, to have a stable work flow, the system needs to have a pull system. In pull system when there is an order system optimize the capacity and responds to the need. In other words demand is pulling the work flow.

Principle 5. Continuous improvement

As value is specified, value streams are identified, wasted steps are removed, and flow and pull are introduced, the process is restarted from the beginning. This is repeated until a state of perfection is reached in which perfect value is created without any waste.

By setting up the steps as described above, a lean management system is built. The last step (continuous improvement) is probably the most important step in the system. The system shows a dynamic behavior rather than an isolate or static behavior. With the help of lean principles and value stream mapping all parts and activities that do or do not add value are known which in turn will help visualization and elimination of the roadblocks. By reviewing the system repeatedly one can try to improve it in order to achieve perfection.

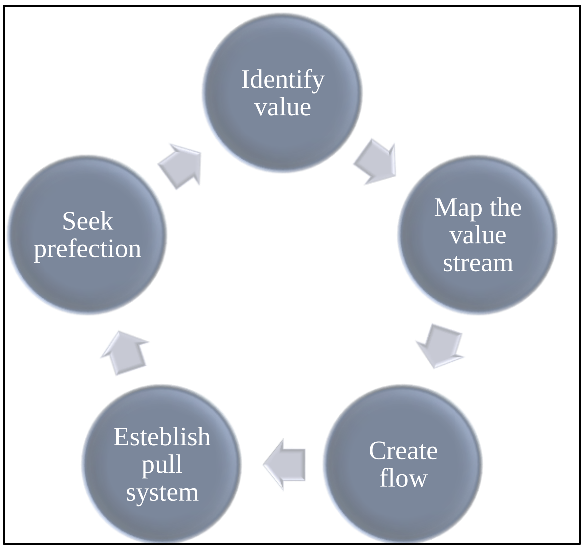

Figure 8.1. Lean principle

8.3. SEVEN WASTE OF LEAN MANUFACTURING

As mentioned in lean principles in Section 8.2. the main idea of Lean Management is to eliminate waste. The most common way to describe this is activities and efforts that are not adding any value to the process. LM describes 7 kinds of waste as listed below:

8.3.1. Waste of Transportation

Transportation is the movement of material from one location to another. This action does not add any value to the process and the final product. Transportation needs manpower to operate and machinery is needed to undertake this costly activity. It may add extra costs to the process and also add time buffers which stop the work flow. Minimization of transportation would eliminate delays, damage risks and reduce the final price of the product.

8.3.2. Waste of Inventory

Any inventory in process which directly does not fulfill customer need. Excessive inventory should be reduced to a level which helps a stable and consistent flow. Poor quality, production delays, production downtime and inflation are the reasons a company produces or holds excessive inventories just in case. Reducing inventories does not mean a company should cut of all its inventory without addressing its problems. In order to reduce excessive inventories a company should first increase the reliability of its supply chain flow. Inventories are costly, need manpower to operate, decrease available space and need extra resources such as machinery to manage it.

8.3.3. Waste of Motion

Any movement which is not short and simple to be overtaken by either workers or machinery is defined as a waste of motion. Extra movement between work places and extra machinery travel between work stations can make a process more costly, interrupt the work flow, cause a stressful work atmosphere and cause damage to machinery.

8.3.4. Waste of Waiting

Waste of waiting is the most important waste that could occur in a process. The waste of waiting can be created whenever a set of independent processes are not synchronized. Waste of waiting can be a delay for a response from other sections, supply delivery delay or time to wait for a professional to repair a machine. Waste of waiting prevents work flow, one of the main principles of Lean Management.

8.3.5. Waste of Overproduction

This can be considered the worst of all seven kinds of waste. Producing more than needed and too early can cause other wastes such as excessive inventories and hide the need for improvement. This is called waste of overproduction. Poor supply plans, long lead time and outsize batches can create waste of overproduction. Waste of inventory is one of the most important causes of overproduction which itself produces many other obstacles in the system. The main idea of Lean Management is to make only that what is required at the time it is required by the customer.

8.3.6. Waste of Over-processing

Using improper methods, oversized equipment, preforming unrequired processes and adding extra unnecessary work in the process can produce waste of over-processing. All these activities could increase the cost of the final product and add extra delay to the process. The goal is to reach a level of processing which is useful and necessary.

8.3.7. Waste of Defects

The waste of defects is described as producing something that does not meet the customer's requirements. Poor quality, design issues, manpower and machinery can produce waste of defects. The cost consequences related to defects are more than expected. Loss of customers, extra paperwork, waste materials and resources and rework or replacement can all be consequences. Waste of defects is better to be prevented than to try to detected.

Eliminating the seven waste of lean from a process is achievable through the implementation of lean principles and lean tools. However, elimination of waste should not be the only focus. Identification of value based on costumer viewpoint and project needs should be achieved by application of lean principles. This approach helps the value adding processes to be more efficient and causes the waste to literally disappear.

8.4. JUST-IN-TIME METHODOLOGY

Just-In-Time (JIT) is a very simple idea but the essential in modern Lean Manufacturing. JIT goal is to decrease the cost by reducing the amount of goods and materials a company holds in stock. JIT strategy tries to aligns raw material orders from suppliers directly with production schedules. The basic theory of JIT is to have just the right amount of inventory, whether raw materials or finished goods, available to meet the demands of the production process and the demands of the end customers. No more, no less. Companies use this inventory strategy to increase efficiency and decrease waste by receiving goods only as they need them for the production process, which reduces inventory costs. This method requires producers to forecast demand accurately. JIT involves:

- producing and delivering finished goods 'just in time' to be sold
- partly finished goods 'just in time' to be assembled into finished goods
- parts 'just in time' to go into partly finished goods
- materials 'just in time' to be made into parts.

The fundamental principles that support JIT is a process should be 'pulled through' instead of 'push through'. This means that production should be for specific customer orders, so that the production cycle starts only once a customer has placed an order with the producer. Stocks are delivered when they are needed. Consequently, this approach requires much more frequent delivery of stocks. adoption of just-in-time (JIT) inventory principles undoubtedly makes a process operation more efficient, cost effective and customer responsive. The less is spent to store and carry inventory, the better one can optimize the transportation and logistics operations.

The closer one gets to JIT, the more beneficial it is for the business. But if it gets too far and reduce inventories very much, the less beneficial it is for your business. Too much or too little inventory leaves you at a competitive (or cost) disadvantage to your competitors. Also, if a raw materials supplier has a breakdown and cannot deliver the goods on time, that supplier can shut down the entire process. A sudden unexpected order for goods may delay the delivery of finished products to clients.

8.5. PUSH AND PULL MANUFACTURING

"Push type" means Make to Stock which means the production is not based on actual demand. "Pull type" means Make to Order which means the production is based on actual demand. The “push system of inventory control” involves forecasting inventory needs to meet process demand. Which material and quantity of goods should be predicted and company should produce enough to meet the demand. If the forecasting process wouldn’t be precise than goods are being stored in warehouses.

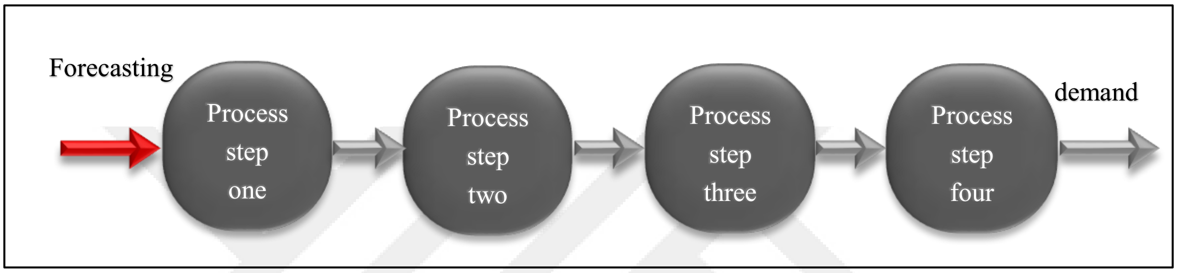

Figure 8.2. Push manufacturing

The “pull inventory control system” begins with an actual demand. company sends an order into the production process at the time a company receives an order for that item. Resources are pulled into the production pipeline only as they are actually needed or requested. A goal of pull-through production is to replace only what has been used, and at the optimal time. With this strategy, companies only make enough product to fulfill demand. One advantage to the system is that there will be no excess of inventory that needs to be stored, thus reducing inventory levels and the cost of carrying and storing goods.

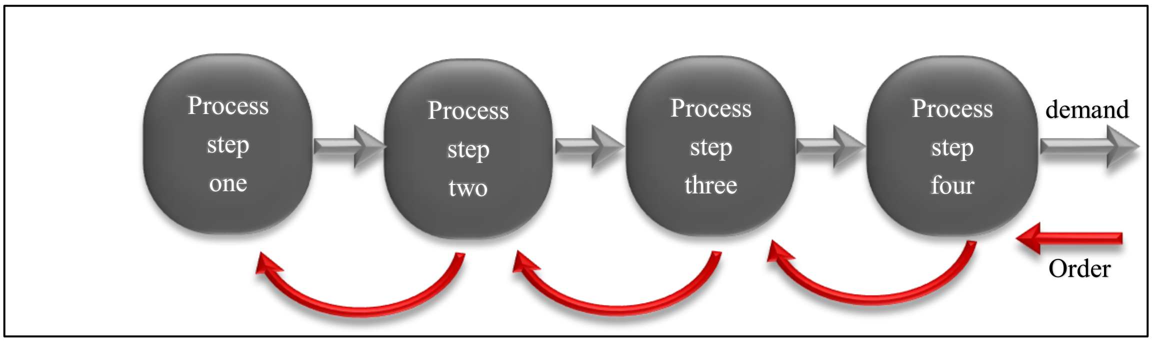

Figure 8.3. Pull manufacturing

In supply chain management, and ideal strategy would be to carry out processes halfway between push type and pull type or by a combination of push type and pull type. It demands a more accurate forecast of demand and adjusts inventory levels based upon actual demand. The goal is stabilization of the supply chain and the reduction of product shortages which can cause delays in process ad loss of time and money. With the push-pull inventory control system, planners use sophisticated systems to develop guidelines for addressing short - and long-term production needs.

8.6. LEAN CONSTRUCTION

The planning, design and construction of building and other infrastructure projects generally involve complex and segmented activities within coordination of several professionals and non-professionals. The construction industry has been always confronted with challenges related to non-value adding activities and processes in its supply chain resulting inefficiencies and low productivity.

One of the main inefficiencies in the construction industry is cost overrun resulting from delays in meeting the deadlines. Materials waste also has been reported as another inefficiency. 14 to 20 percentage cost overrun, 60 to 70 percentage time overrun and about 10 percentage material waste have been estimated in construction industry. Also, material waste has been identified as a serious negative impact on the environment and ecosystem. Additionally, rework which has been the key source of waste in construction causing cost and time overruns. All the issues above together with several others, have made construction one of the main leading environmentally unfriendly industries globally.

There have been many efforts by construction stakeholders with trying new processes, techniques, and management practices toward making industry more productive, less wasteful and more environment friendly. One of such practices is “lean construction” which is borrowed from lean manufacturing and Toyota automobile production focusing to minimize waste, efforts and add value for money to clients or end users.

Applying lean principles in manufacturing and other industries had a remarkable success and it has a potential to be applied also in planning, design and construction sectors. However, applying these principles needs a prefect understanding of Lean tools and principles and their specific application in the planning, design and construction of building and infrastructure projects. Lean implementation begins with leadership commitment and is sustained with a culture of continuous improvement. When the principles are applied properly, dramatic improvements in safety, quality, and efficiency can be achieved at the project.

9. APPLICATION OF THE LEAN PRINCIPLES ON THE SUPPLY MODEL OF ECE COMPANY

After modeling of the supply process and learning about lean management principles and 7 waste, in this chapter we try to apply the seven Lean Waste on the model and eliminate the activities or process which doesn't add any value to the system. After reviewing the model, the waste of waiting and the waste of inventory were detected. Each waste will be removed from the model separately and the new results and graphs will be compared with the existing graphs.

9.1. WASTE OF WAITING

As mentioned before company has a main office in Istanbul which is the headquarters of the all the project inside and outside of Turkey. Also, in every overseas project, the company establishes a local office under the main office authority. It means every operation and purchasing must be approved by the main office. The local office is authorized only for approval of small operations and changes. For material purchasing and supplier related action, the local office must be in touch with the main office in Istanbul.

The process of approval by the main office for each purchasing produces is a waste of waiting in the system. Primarily, sending the orders from the local office (Cyprus) to main office (Istanbul) produces a delay. Secondarily, the process of ordering by main office and transportation of materials produces another delay. Therefore, it is we recommended that, all the procurement team should be located in the local office and the process of ordering, communication with suppliers and transformation of materials should be managed by the local office. Main office could have a supervision on the process but the whole process of ordering should be controlled by local office in order to eliminate the waste of waiting.

In order to eliminate the waste of waiting, the stock of main office is removed from the model. By eliminating this stock, automatically the tow days delay which is result of sending the orders from the local office the main office is being removed from the model. (Figure 9.1)

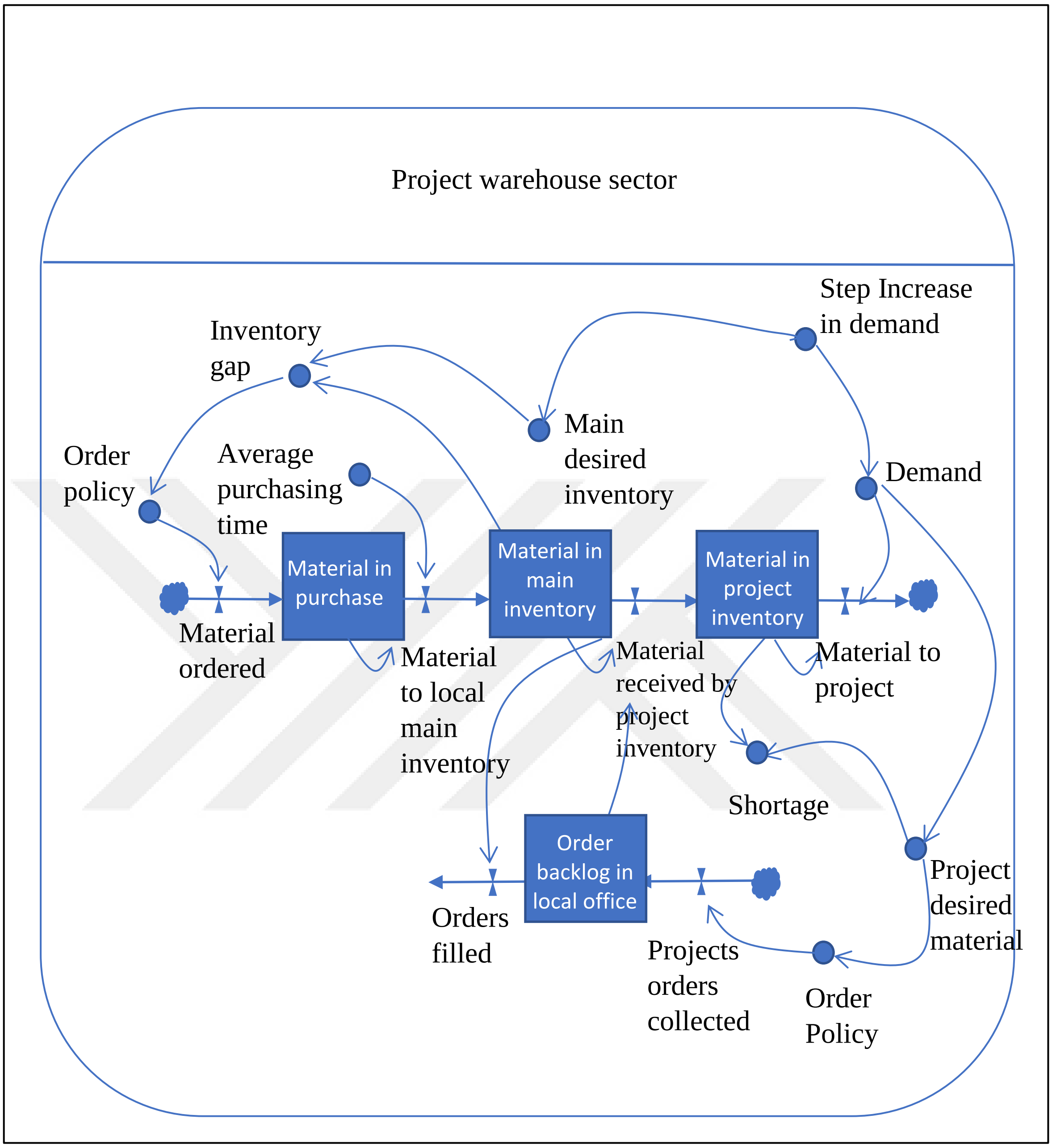

Figure 9.1. New model without the main office sector

As it can be seen in the new model, stock of orders in main office is removed from system. Also, the new system is a one sector system which the process of collecting orders, purchasing, and transporting to main warehouse and to the project warehouse are under the local office authorization and control. The model is simulated over a 100 days period, and the simulation interval (DT) is set at 0.25 days. The unit of time for this model is days. The graphical output for main variables for the base case is provided in figure 9.2 and 9.3.

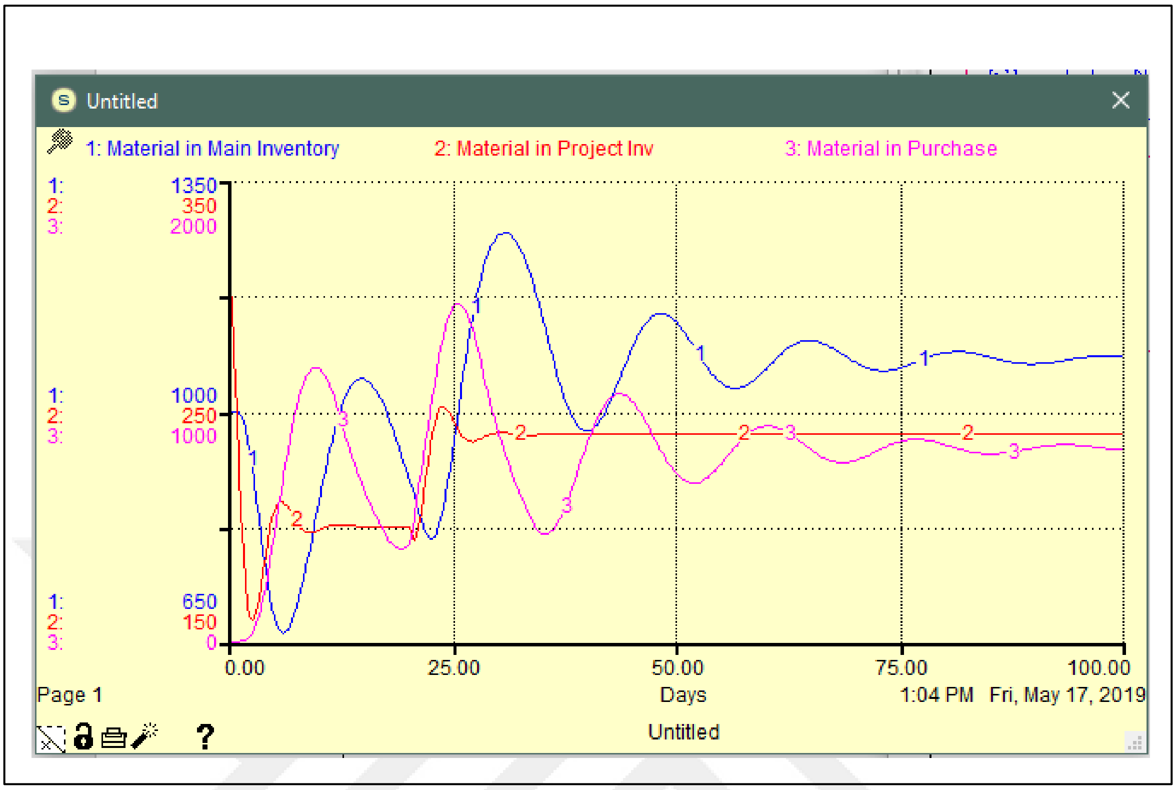

Figure 9.2. Stock behavior

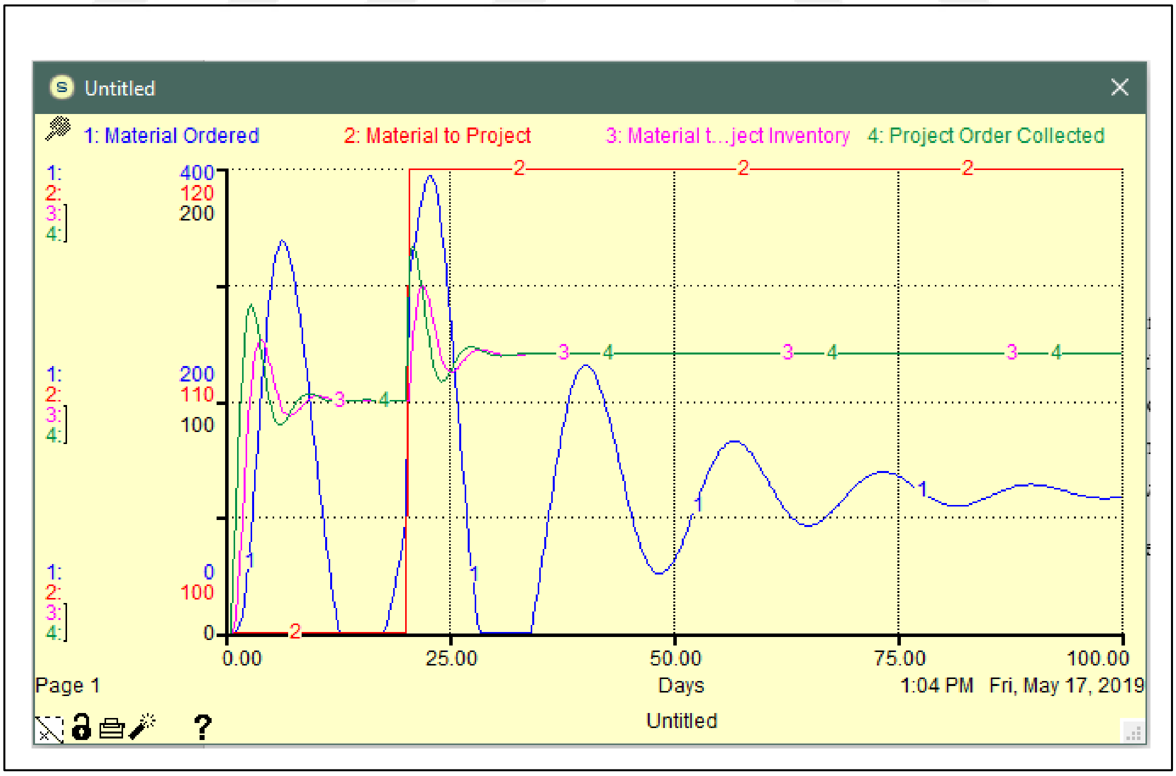

Figure 9.3. Flow behavior

By comparing the new Stock output graphs figure 9.2 with figure 7.1, it can be seen by eliminating the Order in Office stock and consequently the two days delay which has been produced in the system the output is much stable. In first 25 days still, there is some oscillation but we pass the start day of project, system tends to become more and more stable.

Although the Stocks Output shown in Figure 9.2 when compared to base model in Figure 7.1 is improved and almost stabilized, the Flow Output is still having its fluctuation. Especially the Material Ordered flow still has an unstable output during almost 70 % of the 100 days period.

9.1.1. New Model Equations

Material_in_Purchase(t) = Material_in_Purchase (t - dt) + (Material_Ordered - Material_to_Main_Warehouse) * dt

INIT Material_in_Purchase = 0

DOCUMENT: Initially there is 0 package of cement in Purchase

INFLOWS:

Material_Ordered = MAX(Order_Policy,0)

DOCUMENT: The cement order from the supplier is determined by the company order policy, set by the procurement manager.

Material_to_Main_Warehouse = (Material_in_Purchase/Average purchasing time)

DOCUMENT: it takes 7 days for procurement team to purchase the materials and send them to the main inventory.

Inventory Gap = (Desired_Material_in_Main_inv-Material_in_Main_Inventory)

Figure 9.4. New model equations

DOCUMENT: The Inventory gap is the difference between the desired main inventory and actual material in the main inventory.

Order_Policy = (Gap)

DOCUMENT: the order policy is to order a percentage of the inventory shortage every day.

In this case procurement manager ordering all the shortage every time.

Average_ purchasing _time = 7 days

DOCUMENT: it takes 7 days for procurement team to purchase the materials and send them to the main inventory.

Material_in_Main_Inventory(t) = Material_in_Main_Inventory (t - dt) + (Material_to_Main_Warehouse - Material_to_Project_Inventory) * dt

INIT Material_in_Main_Inventory = 1000

DOCUMENT: Initially there is 1000 package of cement in the main inventory

INFLOWS:

Material_to_Main_Warehouse = (Material_in_Purchase/Average purchasing time)

DOCUMENT: it takes 7 days for procurement team to purchase the materials and send them to the main inventory.

Material_to_Project_Inventory = MIN (Material_in_Main_Inventory, Project_Order_Backlog)

DOCUMENT: once the inventory receives an order material are send immediately as long as they are available in the brewery inventory.

Figure 9.4. New model equations (Contd.)

Material_in_Project_Inv(t) = Material_in_Project_Inv (t - dt) +

(Material_to_Project_Inventory - Material_to_Project) * dt

INIT Material_in_Project_Inv = 300

DOCUMENT: initially there is 300 packages of cement in project inventory

INFLOWS:

Material_to_Project_Inventory = MIN (Material_in_Main_Inventory,

Project_Order_Backlog)

DOCUMENT: once the inventory receives an order material are send immediately as long as they are available in the brewery inventory.

OUTFLOWS:

Material_to_Project = MIN (Material_in_Project_Inv, Demand)

DOCUMENT: its assumed that demand for cement is met each day as long as there is sufficient cement in project inventory.

Order_Backlog_in_Local_Office(t) = Order_Backlog_in_Local_Office (t - dt) + (Project_Order_Collected – order_ filled) * dt

INIT Order_Backlog_in_Local_Office = 0

DOCUMENT: Initially there is 0 order in local office.

INFLOWS:

Project_Order_Collected = Project_Order_policy

DOCUMENT: project order is sets by procurement specialist, based of general order policy.

Figure 9.4. New model equations (Contd.)

Project_Order_to_Main_Office = material_to_project_inventory

Demand = (Step_Increase_in_Demand)

DOCUMENT: this is the daily demand for cement by project, assumed to be exogenous from system

Step_Increase_in_Demand = 100+step (20,20)

DOCUMENT: first 20 days project demand is 100 than it increases to 120

Desired_Material_in_Main_inv = Step_Increase_in_Demand*10

DOCUMENT: project manager intends to keep the material in the main inventory, 10 days cover for project.

Desired_Material_in_Project_Inv = Step_Increase_in_Demand*3

DOCUMENT: Project manager intend to keep the material in the project Inventory, 3 days cover for project.

Shortage = Desired_Material_in_Project_Inv-Material_in_Project_Inv

DOCUMENT: The shortage is the difference between the desired material in project inventory and actual material in the project inventory.

Figure 9.4. New model equations (Contd.)

In the previous experiment (eliminating the waste of waiting), the Stock Output is improved and performing well but the Flow Behavior is still not stable enough to call the proposed system as a robust model. This suggests that perhaps another experiment is needed with a different type of order policy by ignoring the shortage in the desired inventories, and basing the order policies on the average daily demand and average daily order filled. This can be achieved in the model, either by removing the linkage from the inventory shortage to the order policy or by setting order fractions equal to zero. It is needed to connect the average demand to the project order collected policies and purchasing policies. In addition, more information should be incorporated into the previous order decisions in the order policies. One of the problems with previous model policies is that information about previous orders placed by the local office were not included in the model. So, in this new experiment the order policy will be based on the current shortage-i.e. the difference between desired project inventory and actual project inventory and orders in local office. In addition, the average daily demand will be included in the reorder policy to ensure a smoother response. The equations for variables "Desired Main Inventory" and "Desired Project Inventory" were also restructured in this last model. So, the linkage from the both variables to the "Step Increase in Demand" were removed and a 10 days demand cover is placed for "Desired Main Inventory" and 3 days demand cover is placed for "Desired Project Inventory". The equations for this restructured project order policy are shown in Figure 9.5.

Project_Order_policy =

MAX(0,Shortage -(Project_Order_Backlog)+average__material_to_ptroject)

Shortage = Desired_Material_in_Project_Inv-Material_in_Project_Inv

Desired_Material_in_Project_Inv=
average__material_to_ptroject*project_inv_cover

average__material_to_ptroject = SMTH1(Material_to_Project,7)

project_inv_cover = 3

Figure 9.5. New order policy equations

Similarly, the purchasing policy is restructured by including information about the current gap between desired and actual main project inventory, and between the material in purchase and average order filled. The restructured equation for the purchasing policies are shown in Figure 9.6.

purchasing_policy = MAX(0,Gap-Material_in_Purchase+ave_order_filled)

Gap = Desired_Material_in_Main_inv-Material_in_Main_Inventory

Desired_Material_in_Main_inv = main_inv_cover*ave_order_filled

main_inv_cover = 10

Figure 9.6. New purchasing policy equations

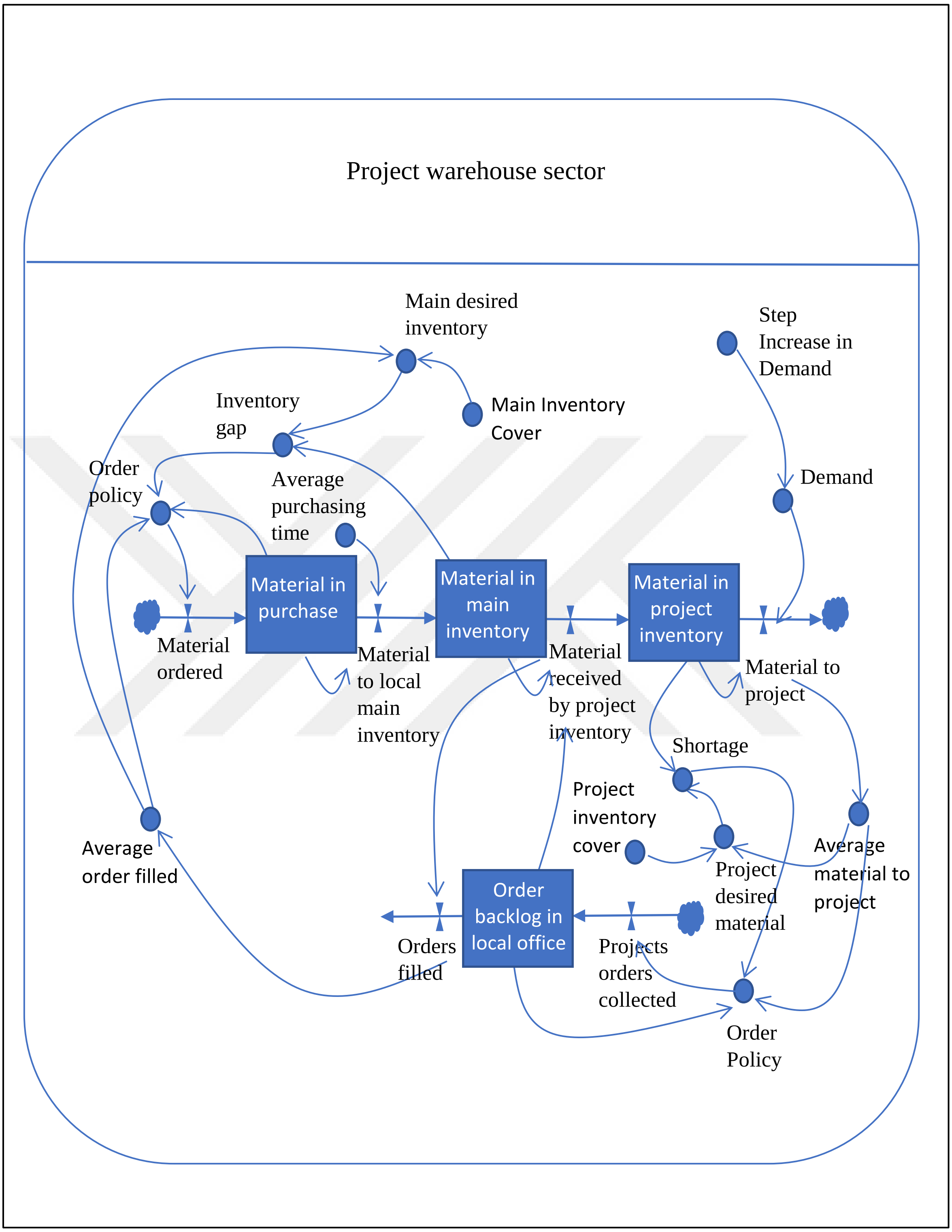

Figure 9.7. Stock flow diagram after applying the new ordering policy

The Stock Flow diagram for the supply process model, including the restructured order and purchasing polices, is provided in figure 9.7.

The model output for the main variables for this policy implementation is provide in figure 20 and 21. We can be reasonably confident that these polices will remain robust in respect of reasonable variations in demand. Now the procurement team can effectively hold stocks of material in the supply system.

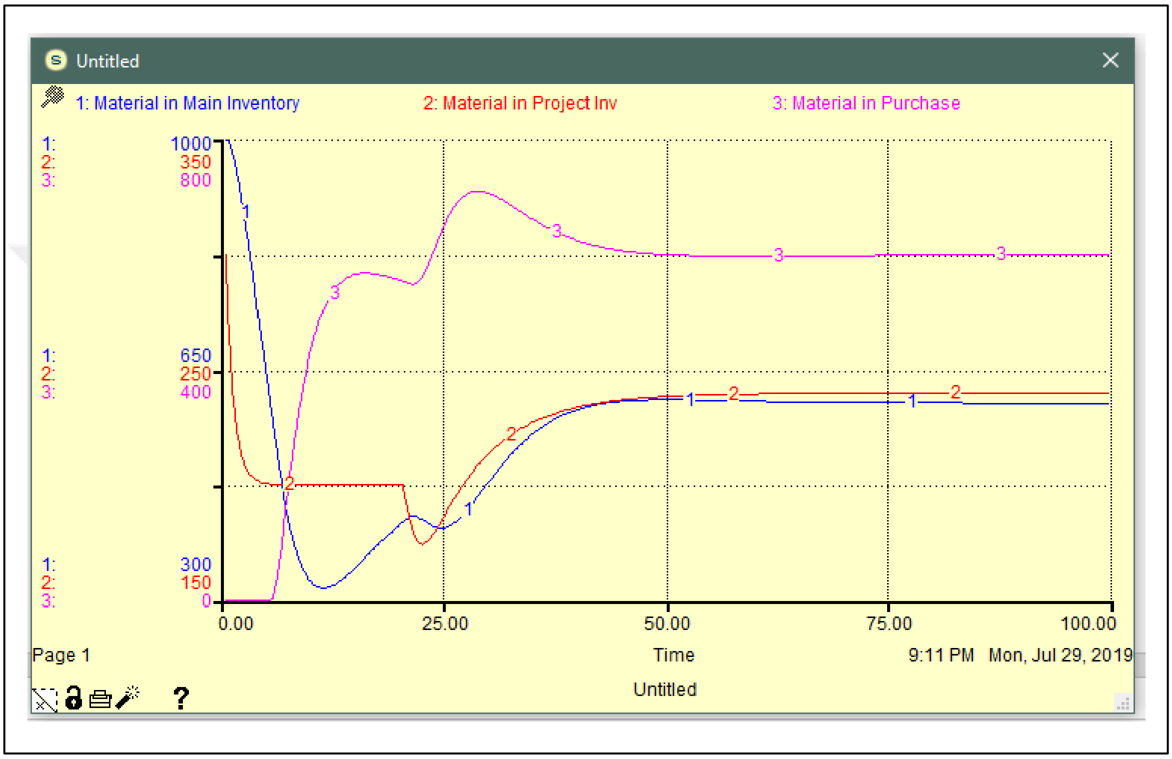

Figure 9.8. Stock behavior

As it can be seen in Stock and Flow Outputs in Figure 9.8, these new policies do result in stability of inventories and reliability of supply the project demand, when compared with the base model in Figure 9.2 Both main inventory and project inventory stabilize at after day 35. It means procurement team has easier job to follow the orders from project. Project inventory has a constant amount of 200 for first 20 days. After the step increase at day 20 there is a small drop in inventory but because now the model is robust enough the model immediately adapt itself to change and settles down.

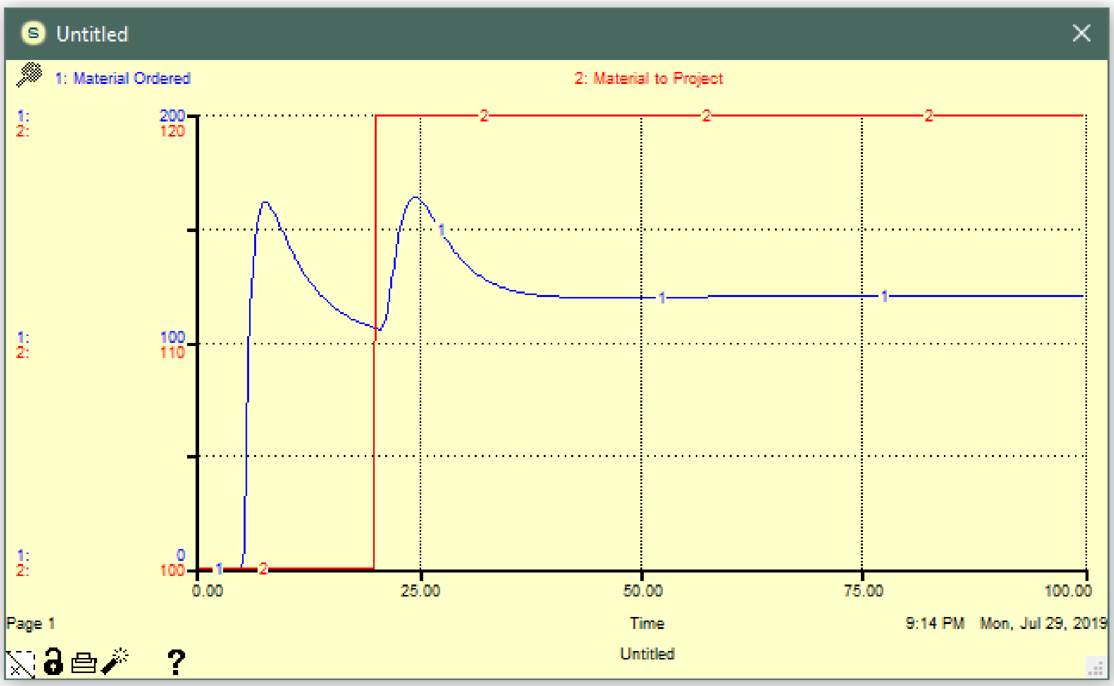

Figure 9.9. Flow behavior

Another variable which is important for procurement team is the flow of Material Ordered. This flow shows in what amount the procurement team should order the material to satisfy the project demand and desired inventories. With the new policies it can be seen that the flow has a constant amount of 120 after day 30. However, there is some fluctuation before day 30 which is the cause of step increase in day 20. Afterall we can say that this model and polices is acceptable as a strong model and tool for procurement team to use for the project supply process.

9.2. SENSITIVITY ANALYSES

Sensitivity analysis is used to determine how “sensitive” a model is to changes in the value of the parameters of the model and to changes in the structure of the model.

In order to execute the sensitivity analyses the value of “function of average purchasing time effect on main inventory.” was chosen. In Figure 9.10. the current average purchasing time is five days. Three days of delay and seven days of delay were chosen to see how it affects inventory behavior.

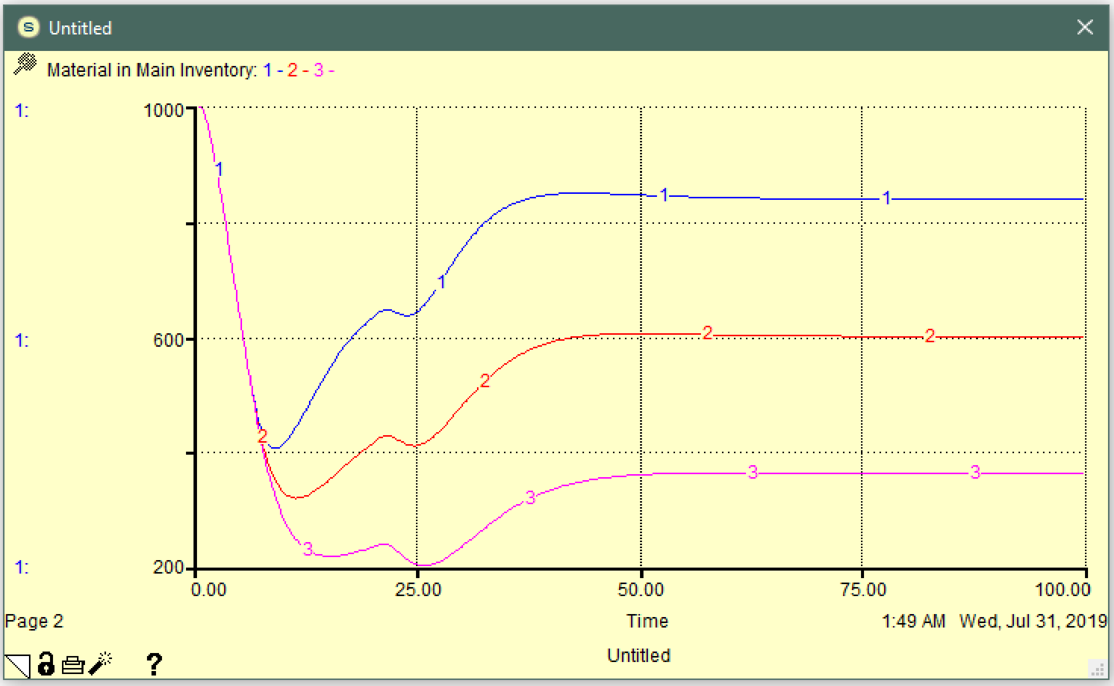

Figure 9.10. Behavior of the main inventory with purchasing time of 3,5 and 7 days

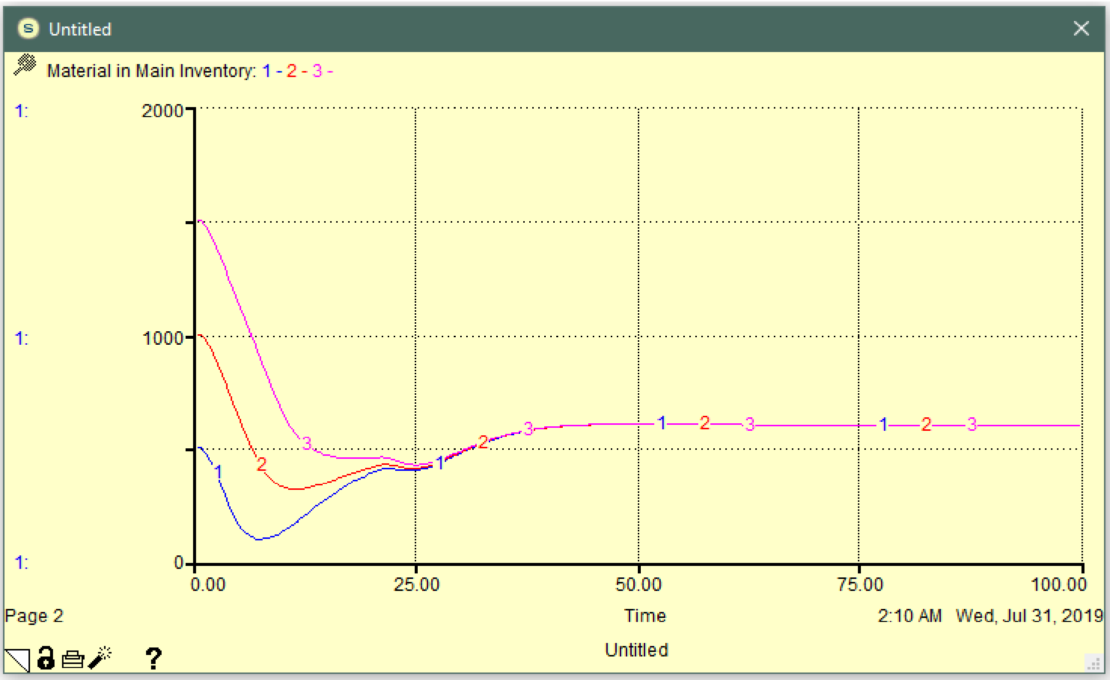

Figure 9.11. Behavior of the main inventory with initial value of 500,1000 and 1500

Inventory is an important issue for every company. Large inventories can increase the cost and small inventories can stop the material flow. Therefore, inventory must remain as stable as possible. Other values chosen to execute the sensitivity analyses is the initial value of the main inventory. In our model the current amount of material in the main inventory is 1000 packages of cement. Two other initial amounts of 500 and 1500 were chosen to show the oscillation of the main inventory in Figure 9.11.

9.3. WASTE OF INVENTORY

Any inventory in process which does not directly fulfill project demand is excessive and should be reduced to a level which helps a stable and consistent flow. Excessive inventory is often the result of a company holding “just in case” inventories, purchased to protect against downtime, delays, poor quality, inflation or other problems. The problem with excess inventory is that it increases costs, reduces available storage space, can become damaged, and extra resources are needed to manage it. Every piece of inventory a company holds has a physical cost associated with it, that cost is shouldered directly by the project profit. In addition to the physical costs of the inventory there also is a host of less obvious costs that are cut directly from a company’s profit, these are areas such as the transportation and movement of this inventory, the space required to store it, the containers to store it in, the administration of keeping track of it, the damage and losses that occur during transportation, even the costs of insuring it. There are many costs associated with this inventory, some not as obvious as others. The lead times as well as the costs will be increased.

One of the reasons for excessive inventory in construction industry is a mistrust of the suppliers, process and even the project demand that causes a company to put in place “comfort stock” in order to give it a buffer if things don’t go according to plan.

Inventory can be observed in manufacturing industry during the different stages of the production process. Raw materials could be ordered in excess of customer requirements due to mistrust of suppliers, or to take advantage of “bulk discounts” to the large amounts of finished goods sitting in your warehouse just in case a customer orders them. However, in construction industry inventories just exist before the construction process mainly due to mistrust in suppliers and also to take advantage of bulk discount.

When ECE company’s supply process is evaluated in these terms, two inventories existed: “The Main Inventory” and “The Project Inventory”. The company policy is to run its supply process under “centralized control”. This means that all the materials and goods which are purchased locally or transported to TRNC should first be stored in the main inventory after which they are sent to the project inventories based on the project’s desired inventory.

The current company policy is producing extra costs and delays such as unnecessary inventory movement, extra employees' motion, extra manual process, extra paper work and most importantly it stops the flow of material to the project.

Reducing inventories does not mean a company should cut off all its inventory without addressing the problems. Otherwise, an organization will likely get in trouble by cutting inventories too much if they haven't first increased the reliability of the supply chain. In other words, reducing the inventories needs a deeper understanding of the process, observing the process at the construction site and also interviewing the procurement team and inventories employees at TRNC. Due to inaccessibility to the construction site and employees the waste of waiting has not been removed from the model. However, it could be a case study for future research.

10. CONCLUSION

The objective of this thesis was to apply the system dynamics approach to ECE company's supply process problem. The model was created based on information and the descriptive models that were provided through meetings with procurement team and managers who were familiar with the supply process at ECE company. The models that were described represented a simplified version of what was actually executed.

Primarily a base model was prepared to observe the dynamic behavior of the company's supply process. The model output showed that Stocks and Flows, which are chosen to be the main 'decision making' factors in the system, rapidly produce fluctuation. Three Stocks of "Material in Purchase", "Material in Main Inventory" and "Material in Project Inventory" and three Flows of "Material Ordered", "Material to Main Inventory" and "Project Order Collected" were chosen to investigate the dynamic behavior of the model.

Following that, the research was focused on the concepts of lean manufacturing and lean construction. Furthermore, lean principles and seven waste of lean were explained. Lean principles were used to review the model. As a result, the waste of waiting and wastes of inventory were detected in the model. It was recommended that, all the procurement team should be located in the local office and the process of ordering, communication with suppliers and transformation of materials should be managed by the local office.

Therefore, the main office located in Istanbul was eliminated from the model and subsequently two days of delay were removed and a secondary model was introduced. By comparing the new model output with the base model output more stable behavior was observed. Although the model behavior has improved and especially stock output graphs showed much more stable behavior, the flows output behavior could not be recognized as a robust behavior.

In addition, a different type of order policy was suggested, ignoring the shortage in the desired inventories. The new policy was based on the average daily demand and average daily order filled. This means more information needs to be incorporated into the previous order decisions in the order policy. One of the problems with previous model policy is that information about previous orders placed by the local office were not included in the model.

With the new policy a third model was suggested. These new policies do result in stability of inventories and reliability of supplying the project demand, when compared with the base model both in main inventory and project inventory.

One of the limitations of this study is that the model can only be applied to a single type of material flow. Cement was chosen in this study because the supply of this material was continuously needed on a weekly basis during the construction. It was further claimed by the procurement team that cement was causing delays during the construction process and that there was a problem in availability and continuous supply of cement. For further research, other materials, such as the supply of reinforcement can be investigated since it is another material that needs to be supplied to the site at even smaller intervals, for example on a daily basis. Since reinforcement needs to be supplied more frequently, system dynamics modeling can produce more effective and positive results for this material. Other materials that may be influential on project success may be chosen based on their criticality or cost.

In conclusion, it is shown in this thesis that, through system dynamics modeling a better control can be achieved on supply of the most influential materials that are needed continuously in construction, problems in the supply chain can be detected and by applying lean management subsequently, a smoother supply system can be defined for the construction process.

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